MACHINE TOOL OPERATION

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PART II

DRILLING MACHINE
SHAPER AND PLANER
MILLING AND GRINDING MACHINES

SPUR GEARS AND BEVEL GEARS

BY

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PREFACE

The preface of Part 1 gives the reasons for preparing this text. Part 1 deals with lathe work, bench work, and work at the forge. An attempt has been made in this volume (Part II) to organize the *fundamental principles of construction and operation* of the Drilling Machine, Shaper, Planer, Milling Machine, and Grinding Machine. A chapter embodying what every machinist should know concerning spur gears and bevel gears is included.

Only fundamentally has this work anything to do with production. Special rapid production machines and tools represent various combinations of fundamental mechanisms, methods and processes. The purpose of this text is to discuss these fundamentals, and build a foundation for rapid production; the same sort of foundation that arithmetic builds for mathematical calculations.

Perhaps a statement regarding the way in which the following text is presented and the reasons therefore should be made here.

First: While there are a great many sizes, types, and kinds of each of the standard machine tools, and while the makers differ in details of design, the fact remains that the primary function, and the basic principles of construction and operation of the given class of machine, are the same regardless of the size or where it is made. Therefore, a well-known example of each of the machine tools under discussion has been selected and described, and typical mechanisms illustrated and explained in such a way as to bring out the general details.

Second: The operator's production, interest and progress are in proportion to his understanding of the basic principles of the construction of the machine he is running—the special mechanical features, feed changes, speed changes, and adjustments of the machine. Consequently, these things have been discussed early in the study of the particular machine.

Third: The broader the student's knowledge concerning the cutting tools used in the given machine, and the quicker he gets a fairly comprehensive idea of the shapes, sizes and characteristics of these tools, the easier and better he can "run the machine." Therefore the cutting tools used have been explained in considerable detail.

Fourth: It is well worth while to look up or reason out correct answers to questions concerning a subject in which one is interested; it not only adds that bit of information to the store of facts one has but makes for progress. Several hundred questions appear in the book as an incentive.

Fifth: Information concerning operations and methods, or suggestions concerning typical set-ups may be expected from a text, and brief instructions regarding the job at hand may be obtained from the foreman or the instructor. However, the student must understand that if he hopes to succeed, he must use his own reasoning powers and develop his resourcefulness. Hence, principles have been discussed and unnecessary details omitted.

Only occasionally has a concrete example of a specific operation been given, because jobs vary daily in every shop. Rather the aim has been to give the reason underlying the particular construction, the principles which determine the right set-up, the "why" of the proper cutting tool for the given purpose, and as far as possible in so brief a text, a survey of established usages and methods of operating the machine in question.

It is hoped that these pages will prove helpful to the young man beginning his work on the various machines; that the text is clear, comprehensive, and interesting enough for the reader to enjoy studying it. Also, that the descriptions and illustrations, the suggestions and the questions, will stimulate to the student to seek further information contained in numerous treatises on machine tools.

HENRY D. BURGHARDT.

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THE DRILL PRESS

CHAPTER I

DRILL-PRESS CONSTRUCTION

1. Introduction.—In every machine shop many sizes and sorts of holes must be made in metal parts. Some of these holes must be very smooth and straight, of an exact size and accurately placed. Others are not so particular as to size or location. In any case, to be produced *efficiently* all holes must be made with the proper tools for the purpose and in machines properly set up and operated. A knowledge of drilling machines and the tools used is one of the most important factors in machine shop practice. A machinist must have this knowledge.

Do not pass over drill-press work too confident that it is easy, that "anybody can run a drill." Such a supposition is about as sensible as an idea that anybody with a reasonable amount of strength can play a piano.

Study the mechanical features of speed changes, feed changes, adjustments of spindle and work table. Get acquainted as soon as possible with the names and uses and the particular characteristics of the cutting tools and their holding devices. Learn to tell by the "feel," by the sound, by the chip, whether or not a drill or other cutting tool is working as it should. Have the set-up look as if a mechanic did the job—neat and trim, with the clamps or stop correctly placed. Most anybody can drill a hole but your job is to know the why of the construction of the machine, the characteristics of the tools used, the successive steps of the operations involved, and how to lay out the work, set up the job, and finish the holes to specifications.

2. The Drilling Machine.—The common mechanical feature of all drilling machines consists of a spindle (which carries the drill or other cutting tool) revolving in a fixed relative position in a sleeve, which does not revolve, but which may slide in its bearing in a direction parallel to its axis. When the sleeve carrying the spindle with the cutting tool is caused to move in the advance direction (usually downward) the cutting tool approaches or is fed into the work, and when moved in the opposite direction the cutting tool is withdrawn from the

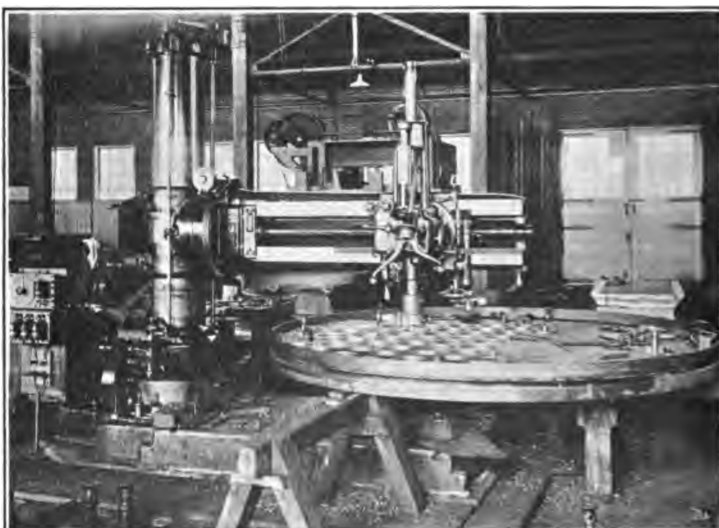


FIG. 1.—A job in a radial drilling machine. *(Courtesy American Tool Works Co.)*

work. In most drilling machines the spindle is vertical and the work is supported on a horizontal table.

Like all other machine tools, drilling machines are of many kinds with a wide range of sizes. The mechanical principles of speed and feed changes in drilling machines differ in no particular respect from those found in lathe construction. All have several speed changes and all except the smaller sizes (sensitive drill presses) are equipped with power feeds.

TYPES OF DRILLING MACHINES

3. Sensitive Drill Press (Fig. 2).—These machines are designed primarily for drilling small holes with hand (sensitive) feed. They are made in various sizes and may have from one to eight spindles. Some of the smaller sizes are set on the bench and are called bench drills.

Fig. 2.—Single spindle sensitive drilling machine. (*Courtesy Henry & Wright Mfg. Co.*)

Fig. 3.—Standard upright drilling machine with spindle reversing mechanism. (*Courtesy Cincinnati-Bickford Tool Co.*)

4. Standard Drill Press (Fig. 3).—This machine, sometimes called upright drill press or simply drill press, has usually six or more speeds and is provided with automatic feeds. The round work table is supported on an arm which is girdled on a finished section of the column of the machine. There are

three ways in which the work table may be adjusted for position. (1) The supporting arm (and table) may be raised or lowered; this provides for different heights of work. (2) The supporting arm may be swung to substantially 90° either side of center, and (3) the table itself, being pivoted at its center, may be swiveled[1] through 360°. The adjustments (2) and (3) in combination provide for locating, directly under the cutting tool, any given spot on the work when the

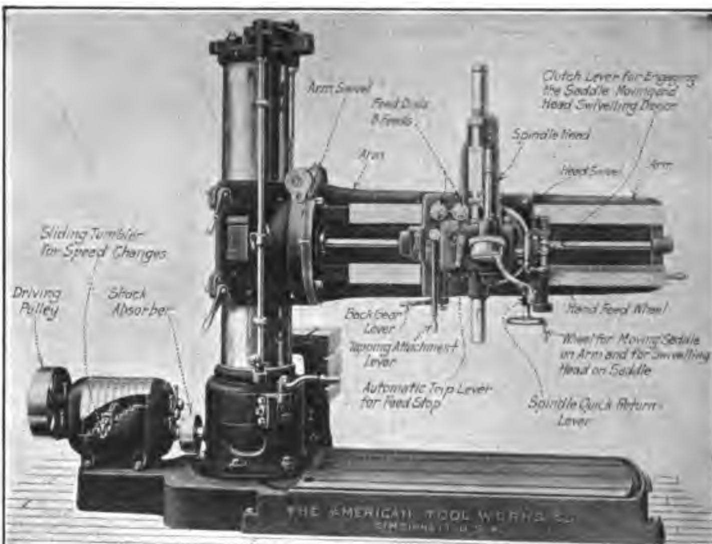


FIG. 4.—Full-universal radial drilling machine.

work is clamped or otherwise impracticable to move about on the table. This type of drilling machine is classified as to size by the diameter of the work table as 15″, 20″, 30″, etc.

5. The Radial Drill (Fig. 4).—This kind of machine is especially useful for drilling several holes in heavy pieces. It is fast supplanting the large upright drill because it is more

[1] *Swivel.*—In machine tools, a construction which permits a part to turn or swing on a column or pivot through more or less of an arc with (usually) provision for clamping in the desired position.

convenient to handle and greater production is possible. The spindle head is mounted on a radial arm which is girdled on the column. The head is adjustable along the arm, and the arm may be swung in a horizontal plane to any desired position within limits. These features permit of quickly locating the cutting tool over any point within a considerable area. Further, the arm may be raised or lowered to accommodate a wide range in heights of work. Radial drills are classified as to size by the length of the radial arm.

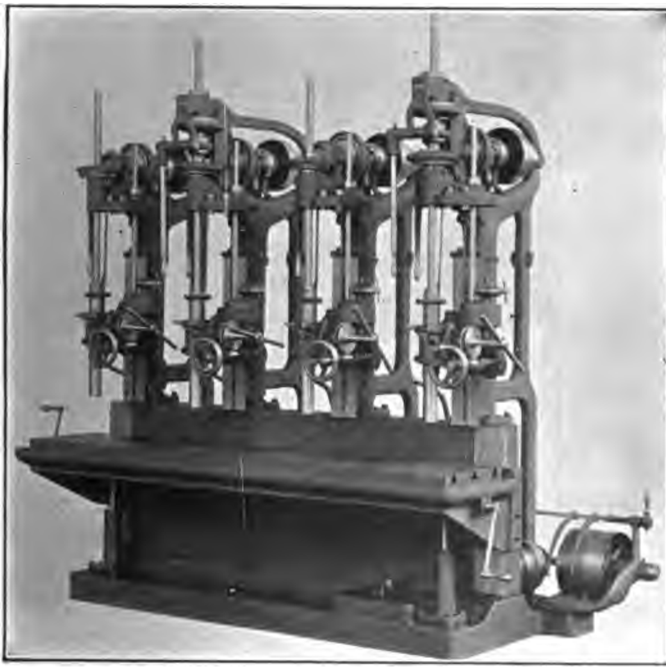


FIG. 5.—Four spindle gang drilling machine with rear shaft drive. Two spindles are equipped with reversing attachment. (*Courtesy Cincinnati-Bickford Tool Co.*)

In the *Plain Radial Drill* the spindle operates only in a vertical position.

In the *Semi-universal Radial Drill* the spindle head is piv-

oted on a saddle which moves on the arm, and by means of a worm and wormwheel swiveling device the spindle may be adjusted to any desired angle in its vertical plane.

The *Full Universal Radial Drill* has the swivel spindle head construction as in the semi-universal, and in addition the arm may be swiveled and clamped in any desired position on

Fig. 6.—Multiple spindle drilling machine. (*Courtesy Pratt & Whitney Co.*)

the arm girdle. These two vertical swivel features with planes at right angles to each other permit of drilling holes at any angle in either plane. Figure 4 illustrates a full universal radial drill.

6. The gang drill (Fig. 5) is a collection in one machine of the essential speed and feed units of from two to eight single drill presses mounted on one base and provided usually

with one vertically adjustable work table extending under all the spindles. The speed and feed units, also the vertical adjustments of the heads, are individual and independent. One or more of the spindles may be provided with the reversing gears or "tapping attachment." This type of machine is a manufacturing machine and is primarily intended for work held in a jig which may be easily slid from spindle to spindle for successive operations. A very wide range of sizes and types of gang drills are manufactured.

7. The adjustable multiple spindle drill, a type of which is illustrated in Fig. 6 is a drilling machine containing usually 16 to 20 spindles operated simultaneously from one driving shaft. The spindles are supported in brackets which are adjustable horizontally with a considerable range, and the locating of drills in the relative positions desired can be done easily and quickly. The spindles are also adjustable vertically, which feature takes care of uneven wear of drills, etc. In most machines of this type the drill head is stationary, and the feed is accomplished by moving the work table, either automatically or by hand or foot power. The work table unit is counter-balanced by a permanent weight within the column, and the weight of the work and the jig is counter-balanced by means of auxiliary weights similar to those used in weighing machines.

Fig. 7.—Auxiliary multiple spindle drilling head. (*Courtesy Hoefer Mfg. Co.*)

When manufacturing large numbers of duplicate pieces containing two or more holes of substantially the same size, this type of machine is a time saver. A drill jig must be used to give the greatest accuracy and efficiency.

Several types of auxiliary multiple spindle drilling heads are made that have proved very efficient in rapid drilling of small holes in duplicate pieces. These attachments may be used in almost any kind of drilling machine of sufficient size. Figure 7 illustrates one type.

8. Parts of the Drill Press.—In Fig. 9 a standard drill press is illustrated, and the parts are numbered and named. Brief descriptions of the mechanisms are given in the text. These part names and descriptions apply practically to any drill press and similar constructions are found in all drilling machines. Do not be satisfied merely to operate the machine —real satisfaction comes in knowing the construction and capabilities of the machine.

9. Drill-press Drive.—Power is transmitted from the line shaft to the "loose" pulley (1) (Fig. 9). By moving the belt shifter (3) the lower cone pulley, keyed to the same shaft as the "tight" pulley is caused to rotate. The lower and upper cone pulleys (4) and (5) are connected by belt, and having the clutch (8) "in" (lever (10) pulled toward operator) and the back gears (11) "out" as many direct speeds of the spindle driving shaft are obtainable as there are steps on the cone pulleys. (In the drill press illustrated in Fig. 8, there are four speeds.) By changing the position of the clutch (lever (10) pushed away from operator) and putting back gears "in," as many indirect or back-gear speeds of the driving shaft are obtainable as there are steps on the cone pulley. Since motion is transmitted from the spindle driving shaft through the bevel gears (13) to the spindle (which is feathered in the hub of the lower gear) there are, therefore, eight spindle speeds in the drill press illustrated. These speeds are practically in geometrical progression from 18 r.p.m. to 336 r.p.m.

10. Feeding Mechanism.—The spindle (17), Fig. 9, revolves in and is carried up or down by the sleeve (18) which may slide vertically through its bearing in the head, the vertical movement being accomplished through a pinion engaging a rack (27) fastened to the sleeve (for detail of worm and wormwheel see Fig. 8).

The pinion shaft may be moved by hand or power. The handle (28), Fig. 9, on the pinion shaft is provided for sensitive hand feed, and also for quickly advancing or returning the spindle (first tripping feed-trip trigger (31) to disengage worm from wormwheel). The regular hand feed is accomplished by means of the hand wheel (29) through the wormwheel (26) (first placing feed-change handle (23) in neutral position).

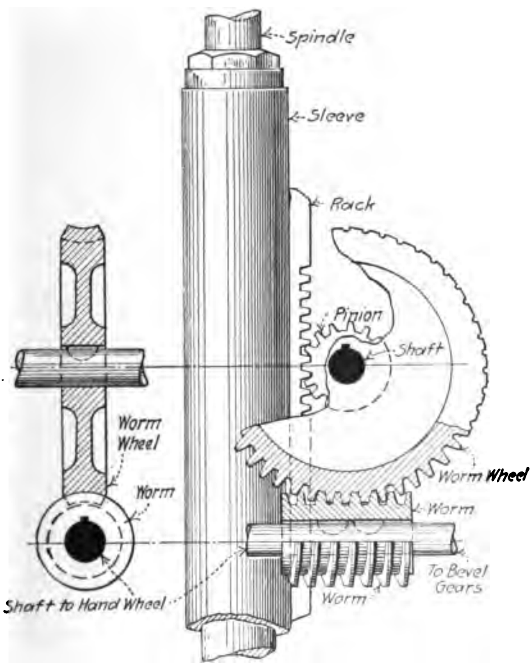


FIG. 8.—Shows worm, wormwheel and rack for moving the spindle sleeve and spindle to feed the cutting tool.

The automatic feed is obtained from the revolving spindle through the gears (20) to feed shaft (21) through gear box (22) through bevel gears (25) through worm and wormwheel (26) to pinion and rack. The automatic feed stop (30) may be adjusted to disengage the feed at any predetermined depth.

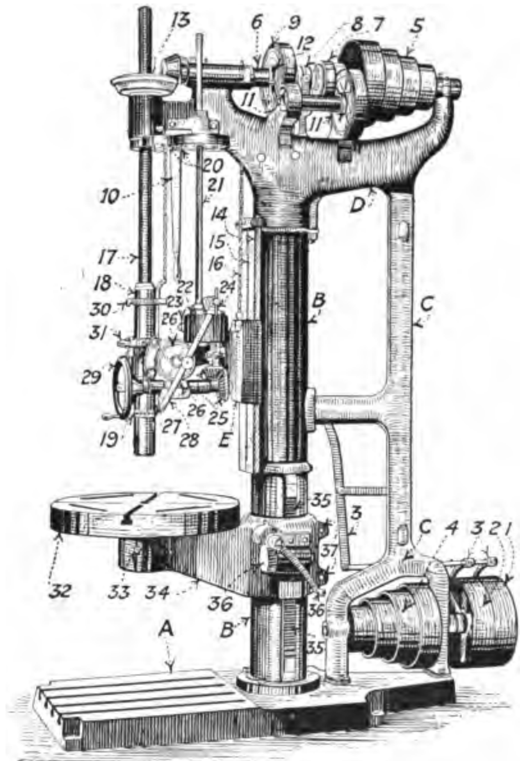


FIG. 9.—Drill-press. (*Cincinnati-Bickford.*)

PARTS OF THE STANDARD DRILL PRESS

A. *Base.*

B. *Column.*

C. *Driving pulley support and brace for yoke.*

D. *Yoke.*

E. *Head.*

Driving Mechanism.

1. *Loose pulley.*
2. *Tight pulley.*
3. *Belt shifter.*
4. *Lower* (driving) *cone pulley.*
5. *Upper* (driven) *cone pulley.*
6. *Spindle driving shaft.* In machines which are not equipped with back gears the cone pulley (5) is fastened directly to this shaft. In machines with back gears the cone pulley, together with the friction clutch cup (7), runs freely on the shaft, but may be connected directly (for faster series of speeds) by shifting the clutch (8) to expand the friction ring in the friction clutch cup, or indirectly (for the slower series of speeds) by shifting the clutch to opposite position expanding friction ring in face gear (9) thus driving through back gears (10) (detail Fig. 11).
7. *Friction clutch cup.*

8. *Friction clutch.* This sliding member of the clutch carries a long key or wedge for expanding the friction ring in (7) or (9). This key slides in a groove cut in the hub of the friction-clutch bush which is keyed to the spindle driving shaft.

9. *Face gear.*

10. *Friction-clutch operating lever* (pulled toward the operator for direct speeds, pushed away for back gear speeds, middle position neutral).

11. *Back gears.*

12. *Back-gear handle* (operates back-gear eccentric shaft to engage or disengage back gears).

13. *Spindle driving gears* (bevel) for transmitting motion from the driving shaft (6) to the spindle (17).

Head, and Feeding Mechanism.

14. *Finished face of column* on which the head may be adjusted vertically.

15. *Rack* for adjusting head vertically (rack pinion is located inside of head casting. Pinion operating handle and head clamping screws are on left hand side of head).

16. *Head counterweight chain;* counterweight within the column.

17. *Spindle.*

18. *Sleeve.*

19. *Ball thrust-bearing* between spindle and sleeve.

20. *Feed gears* (for transmitting motion from spindle to feed shaft).

21. *Feed shaft.*

22. *Feed box* (for detail see Fig. 10).

23. *Feed-change handle* (for clutch).

24. *Feed-change handle* (for spring key).

25. *Feed gears* (bevel).

26. *Feed worm* and *wormwheel. Feed-rack pinion* (not shown) is on same shaft as wormwheel and meshes with feed rack (27) (detail Fig. 8).

27. *Feed rack* (attached to sleeve).

28. *Handle* for quick advance or return of spindle.

29. *Wheel* for hand feed.

30. *Feed stop* (adjustable).

31. *Feed-trip trigger* (tripped by feed stop (30) or by hand). Releases lever which holds worm in mesh with wormwheel allowing it to drop out of mesh, thus stopping automatic feed.

Work Table and Supporting Arm.

32. *Work table* (may be swiveled on its center through 360°).

33. *Table clamping screw.*

34. *Table arm,* adjustable vertically on finished portion of column, also girdled and may be swung horizontally through considerable more than 180°.

35. *Table elevating rack.*

36. *Wormwheel, worm,* and *handle* for moving table vertically. (Rack pinion (not shown) on same shaft as wormwheel.)

37. *Table-arm clamping screws.*

Six feeds are available through the quick change gears enclosed in the gear box (22) by changing the position of the handles (23) and (24). This mechanism, described in the following paragraph, is especially interesting because it is an excellent example of the use and value of the "spring key" in machine construction.

11. Quick Change Gear Box.—The development of the mechanism within the gear box is shown in Fig. 10. The positive clutch C is feathered on the feed shaft (21) and is operated by the handle (23), through the eccentric at X, to engage the clutch teeth in the hub of either of the driving gears A or B which otherwise revolve freely on the shaft. The cone of gears D, E, F and G are keyed to the intermediate

shaft and revolve with it, the gears *E*, *F* and *G* engaging respectively the driven gears *H*, *I* and *J* which revolve freely on the driven shaft. The key *K* is hinged on a pin in a slot in the lower end of the rod *R*. This rod may slide freely in the hollow driven shaft *T* and is operated by a handle (24, Fig. 9) through the pinion *P* which engages the teeth similar to rack teeth formed by cutting grooves around the upper end of the rod. The force of the spring *S* serves to push the

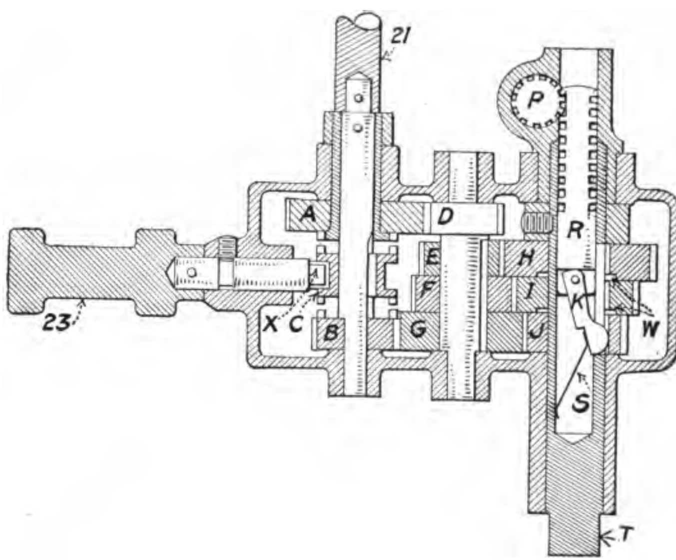


FIG. 10.—Vertical section through feed box of Cincinnati-Bickford upright drill.

key *K* through a slot in the hollow shaft and into the keyway of a driven gear, *H* or *I* or *J* as desired. Hardened washers *W* are placed between the gears to prevent the key from engaging two gears at the same time.

One series of feeds (the slower series) is obtained by engaging the clutch *C* with the driving gear *B* and engaging the sliding spring key in the different driven gears. For example, the slowest feed is obtained by engaging the clutch *C* in gear *B* and the spring key in gear *H*. Motion is transmitted through a compound gear train, from smaller gear *B*

to the larger gear G and from the smaller gear E to the larger gear H causing the driven shaft T to revolve much slower than the feed shaft (21).

The faster series of three feeds is obtained by engaging the clutch C with the driving gear A and engaging the key in the different driven gears. For example, the fastest feed is obtained by engaging the clutch C in gear A and the spring key in gear J. Motion is transmitted through a compound gear train, from the larger gear A to the smaller gear D and from the larger gear G to the smaller gear J. The gear box is designed to give six positive feeds, in fractions of an inch per revolution of the spindle from .006″ slowest to .039″ fastest in geometrical progression.

12. Reversing Mechanism or "Tapping Attachment."—Most of the upright and radial drills are now provided, if so

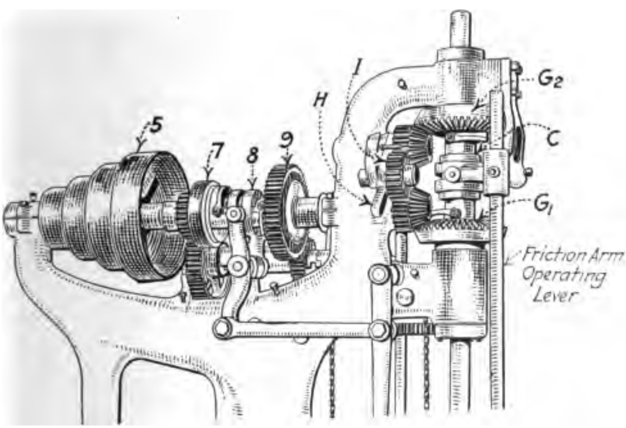


FIG. 11.—Spindle driving gears and reversing gears or "tapping attachment," shown with gear guards removed. By means of the friction clutch, the direct and indirect (back gear) speed mechanisms and the reverse gears, work may be drilled at fast speed, tapped at slow speed and the tap reversed and withdrawn at fast speed. (*Cincinnati-Bickford Tool Co.*)

desired, with a spindle-reversing mechanism, consisting of a clutch and suitable gears, which is known as the tapping attachment. Figure 11 illustrates the tapping attachment provided, at the option of the purchaser, as an integral part of the drill press shown in Fig. 9. The larger bevel gears G_1 and G_2 revolve freely in their respective bearings in opposite directions. The friction clutch member C is feathered on the spindle and revolves when engaged with G_1 to give the regular

rotation to the spindle, and when engaged with G_2 to give the reverse. When the clutch is in midway (neutral) position the spindle does not turn.

The friction-clutch drive permits of starting or stopping the spindle while the machine is running at any speed, and this is equally true when the intermediate gear I is raised out of mesh (by handle H) and the reversing mechanism is not being used. This feature alone, as a time saver, is worth the added cost of the attachment.

Questions on Drill-press Construction

1. Clean the taper hole in the drill-press spindle. Why is it especially dangerous to clean a taper hole in a revolving spindle? How do you clean this hole? Why must it be clean and dry?

2. Clean the taper shank of, say, a 1" diameter drill, be sure it is free from nicks and put it in the spindle, arranging the tang of the drill to enter the slot in the spindle. Place a suitable block of wood on the table and using the handle for quick advance of spindle bring the point of the drill sharply against the block three or four times. How does this serve to drive the drill home?

3. Clean the finished portion of the column on which the table arm is supported, loosen the binding bolts and lower the table. Raise the spindle head to its highest position. What is the maximum height of the work that may be drilled on the table?

4. Swing the table to one side. How much higher work may be held on the floor plate than can be held on the work table?

5. How is the table raised or lowered? How is it swung to the right or left on the column? How is it turned on its own axis?

6. Why, in some drilling machines, is provision made for raising or lowering the spindle head on the front of the column?

7. What is the maximum amount of the adjustment of the spindle head?

8. How is the weight of the head counter-balanced?

9. In operation, the drill-press spindle revolves in the spindle sleeve. Does the sleeve revolve?

10. How does the sleeve move in its bearing? What does it carry with it?

11. How is the spindle supported at its upper end? How is it made to revolve? Why is a long keyway or "spline" cut in the spindle?

12. How is the drill press started and stopped? What do you mean by a loose pulley? A tight pulley? How is a loose pulley oiled?

13. How many direct spindle speeds has this drill press? How are they obtained? Has it any back gears?

14. How many spindle speeds has this drill press?

15. When are the back gears used? Why?

16. How are the back gears engaged?

17. Is it safe to engage the back gears when the machine is running? Give reason.

18. What is the use of the rack fastened to the spindle sleeve? What engages it?

19. How is the spindle caused to move in a downward direction by hand? What is this called?

20. How many methods of feeding by hand are provided in this machine? Which is the most sensitive? Why? Which requires the least effort? Why?

21. Examine the mechanism that transmits motion from the spindle driving shaft to the feed-rack pinion. How do you change the speed of the feed rod without changing the spindle speed? How many changes may be made? How many power feeds has this drill press?

22. How is the power feed engaged?

23. How does the worm and wormwheel operate to give a slow motion to the feed-rack pinion?

24. How is the power feed released? Has it an automatic release?

25. How is the automatic release set for a required depth?

26. The amount of feed is a certain number of thousandths of an inch per revolution of the spindle. How many thousandths per inch is the maximum feed that can be obtained on this drill press? What is the minimum feed?

27. What kind of a hole is in the end of the spindle? Why?

28. What is a sensitive drill press? Why is it so named?

29. What type of drilling machine is usually called simply "drill press?" Why?

30. What is a radial drill? Semi-universal radial drill? Universal radial drill?

31. What is the advantage of a radial drill?

32. What is the value of a multiple spindle drill?

33. What mechanical feature is common in all drilling machines?

34. How are drilling machines classified as to size?

35. What is the difference between an eight-spindle sensitive drill and a multiple drill?

CHAPTER II

DRILLS AND DRILLING

13. Drilling Machine Operations (Fig. 12).—*Drilling* is the operation of producing a circular hole by removing solid metal. The cutting tool used is called a drill.

Reaming is the operation of sizing and finishing a hole by means of a cutting tool (reamer) having several cutting edges. Reaming serves to make the hole smoother, straighter, and more accurate.

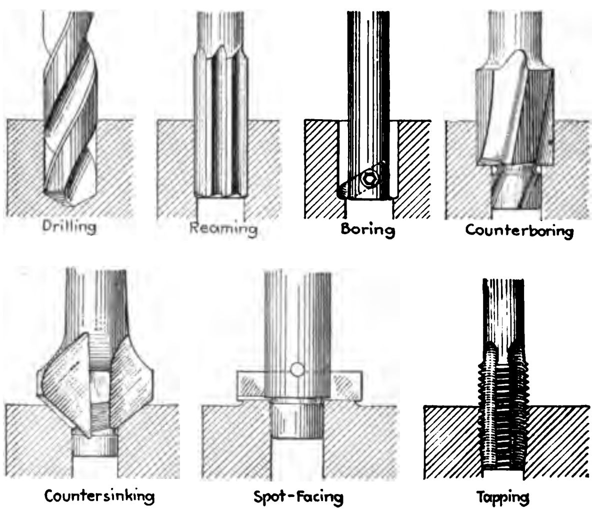


FIG. 12.—Illustrates drilling machine operations.

Boring is the operation of enlarging a hole by means of an adjustable cutting tool with one cutting edge.

Counterboring is the operation of enlarging the end of a hole cylindrically, as for a recess for a fillister head screw.

Countersinking is the operation of making a cone shaped

enlargement of the end of a hole, as for a recess for a flathead screw.

Spot facing is the operation of smoothing and squaring the surface around the end of a hole, as for the seat for a nut or the head of a cap screw.

Tapping is the operation of forming internal screw threads by means of a master tool called a tap. To withdraw the tap by power in a drill press requires a reversing attachment or "tapping attachment."

14. The Twist Drill.—The drills most commonly used are twist drills. The twist drill is probably the most used and

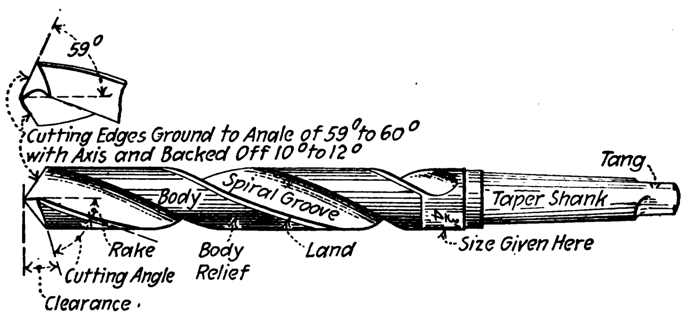


FIG. 13.—Taper shank twist drill.

most efficient cutting tool in the shop. Obtain a twist drill and referring to Fig. 13 note carefully the following features: It has two cutting edges or "lips" the upper faces of which are formed by milling two opposite grooves spirally (twisted) in a cylinder. The bottom or end faces of the cutting edges are at an angle of approximately 60° with the axis. It has been found by experience and test that the angularity of the cutting edges of about 120° with each other (theoretically 118°) offers the best angle for centering the drill and keeping it central without any tendency to wedge. These angular faces are "backed off" or "relieved" for clearance, and when the cutting edges become dull the end faces only are ground as hereafter explained. The spiral groove (flute) is milled at an angle of about 20° to

25° with the axis of the drill, thus giving the rake, and the cutting edge when properly ground is relieved about 10° to 12° on the end, consequently the *cutting angle* is substantially 55° to 60° which is correct for cutting iron and steel. Another advantage of the spiral flute lies in the fact that the chips work out readily during the cut making unnecessary the removal of the drill from the hole to clean it from chips even when drilling a fairly deep hole. Note that after the flutes

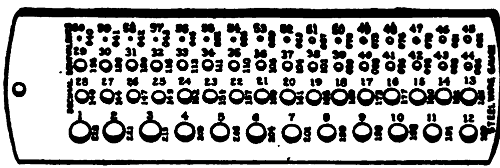


Fig. 14.—Drill gage.

are cut the remaining portion of the surface of the body is relieved and only a narrow "land" is left. This body clearance reduces the friction of the drill in the hole. The thinnest section of the body of the drill (between the bottoms of the flutes) is called the "web."

Twist drills are made in number sizes; No. 1 (.228″ dia.) to No. 80 (.0135″ dia.). They are made in letter sizes; A (.234″ dia.) to Z (.413″ dia.) (see Table 18). They are also made in sizes ranging by 64ths of an inch from 1/64″ to 4″ or

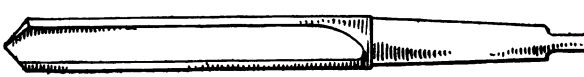


Fig. 15.—Taper shank straight fluted drill.

more, and in metric sizes, ranging from .4 mm. (.0157″) to 50 mm. (1.068″) by .1 mm. (about .004″) on the smaller sizes, and by .5 mm. on the larger sizes. The smaller drills are not marked and the size is found by the use of a drill gage, Fig. 14.

15. The Straight Fluted Drill.—For drilling brass, copper or other soft metals a drill with rake (a twist drill) has a tendency to "dig" or "grab." A straight fluted "Farmer" drill (Fig. 15) is the best to use for soft metals but a twist

drill may be used if the front of the lips are ground as shown in Fig. 16. It is also advisable to use a drill without rake when drilling very thin stock owing to the tendency of the drill to "hook into" the work when it is breaking through. A drill ground in this manner is very effective for drilling unannealed steel or "hard spots" in cast iron when turpentine is used as a lubricant.

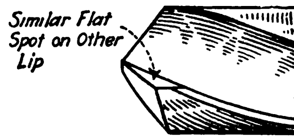


FIG. 16.—Twist drill ground for brass.

16. The Flat Drill.—Occasionally when it is required to drill a hole of a size for which a twist drill is not at hand, it is convenient to know that a flat drill (Fig. 17), that will do good work may be made easily and quickly. A piece of round tool steel of a suitable size is forged flat on one end, centered, the shank turned straight or taper as desired, and the narrow sides of the flat portion turned to the size required. If the drill is of a sufficient size to warrant the extra turning,

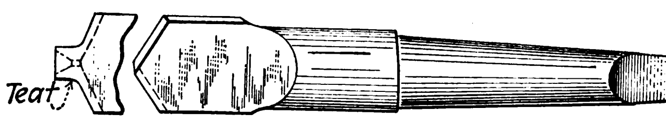


FIG. 17.—Home made flat drill.

the cutting edges can be turned to the included angle of 120° leaving a teat which may then be filed off. If greater accuracy is required the shank and "body" may be left large enough to grind on centers after hardening and tempering.

FIG. 18.—Three-fluted drill.

In this case the teat will of course be left on until the last operation, namely, backing off and sharpening the cutting edges.

17. The three-fluted drill (Fig. 18) so called because it resembles a twist drill, would perhaps more properly hav

been named a three-tooth spiral reamer since its function is enlarging cored, punched or drilled holes. It will not drill the initial hole but being very sturdy and having wide cutting edges it is an efficient tool when a hole must be considerably enlarged.

18. How the Cutting Tools Are Held.—The cutting tools used for any of the drilling-machine operations (except tap-

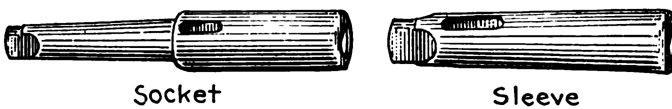


FIG. 19.—Cutting tools with taper shanks that are too small to fit the taper hole in the spindle of the machine are held in a smaller taper hole in a socket the shank of which fits the spindle hole. If the socket makes too long an extension a shell socket or "sleeve" may be used.

Sockets and sleeves are made in all necessary sizes, No. 1 to No. 2; No. 1 to No. 3; No. 3 to No. 4 etc., the first number denoting the size of the taper hole and the second number the size of the taper shank. If a suitable socket or sleeve is not at hand, a combination of socket and sleeve or of two sockets or two sleeves may be used.

ping) may be made either with straight shanks or taper shanks (Morse standard). It is not usually considered economical to have the smaller sizes (for example, drills or reamers under ½″) provided with straight shanks because they can be conveniently and firmly held in a chuck (Figs. 21 and 22) and the extra cost of the taper shank on these sizes is unnecessary. In the larger sizes the difference in cost between straight and taper shanks is not as great and it is nearly always more convenient to hold them by means of the taper shank.

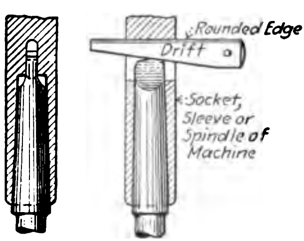


FIG. 20.—Illustrates how the taper shank with tang is held in taper hole, and also the use of the drift to remove the taper shank from the taper hole of the socket, sleeve, or spindle as the case may be.

19. Sockets and Sleeves.—The drilling-machine spindle is provided with a Morse standard taper hole of a size in proportion to the size of the machine. Several sizes of drills,

for example, have shanks which will fit the spindle,[1] others are too small, and to step the sizes, sockets or sleeves, Fig. 19, are used. A taper key or "drift" is used as shown in Fig. 20 to remove the taper shank from the taper hole. Do not use anything but a drift for this purpose and use the rounded edge against the rounded end of the hole.

The taper shanks of drills, reamers, counterbores, etc., and also of the sockets and sleeves, have the end flatted to form a "tang" which fits in a suitable slot at the end of the taper hole

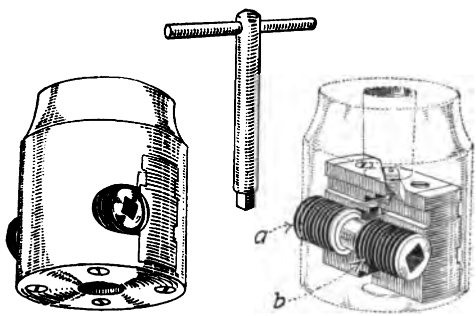


Fig. 21.—Standard type of two jaw drill chuck. The jaws are fitted to move freely in a slot cut diametrically across the lower end of the body. The movement of the jaws is controlled by a screw arranged within the body to fit suitable threads cut in one side of each jaw. One end *a* of the screw is cut right hand while the other end *b* is cut left hand, consequently, when the screw is turned, the jaws move uniformly toward or away from each other. The clamping faces of the jaw are V shaped lengthwise, to centralize the shank of the cutting tool, and notched alternately crosswise, thus fitting more or less of a distance, one within the other, in order to grip equally well a wide range of sizes.

in which the shank is held (see Fig. 20). The purpose of the tang is to help drive the drill since the hold of the taper alone is not sufficient. It must be understood, however, that the tang alone is not sufficient to drive the drill or other cutting tool and consequently the taper shank and hole must be properly fitted, clean, and dry, and the shank firmly driven

[1] The range of sizes of drills provided with a given size of shank is usually as follows: Sizes up to $9/16''$ diameter No. 1 Morse taper; sizes $37/64''$ to $29/32''$ No. 2 Morse taper; sizes $59/64''$ to $1\frac{1}{4}''$ No. 3 Morse taper; sizes $1\frac{17}{64}''$ to $2''$ No. 4 Morse taper; sizes $2\frac{1}{64}''$ to $3''$ No. 5 Morse taper; sizes $3\frac{1}{16}''$ to $4''$ No. 6 Morse taper.

home or the taper will not do its share and the result will be a twisted-off tang.

20. Drill Chucks (Figs. 21 and 22).—A chuck is a gripping device with two or more adjustable jaws set radially. A drill chuck is made especially for holding *straight-shank* drills or other cutting tools in the spindle of the machine and is itself

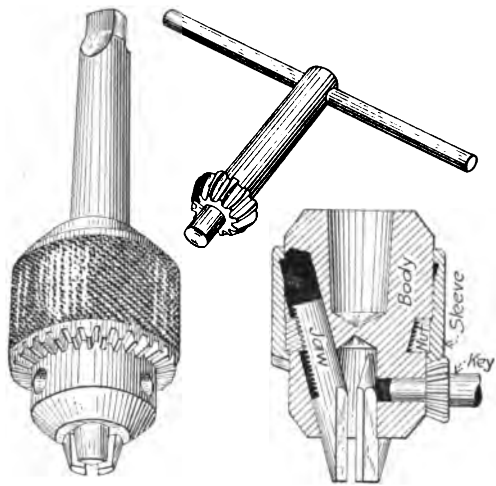


FIG. 22.—Jacob's Drill Chuck. One of the best and most popular chucks in the shop. The chuck may be taken apart by forcing the sleeve off over the jaw end of the chuck, when the nut which is made in halves may be taken out leaving the jaws free. Have the jaws partially closed before forcing off the sleeve.

provided with a *taper shank* which fits the taper hole in the spindle. They are made in various sizes, and a series of three or four chucks will hold drills from the smallest size up to 1″ in diameter.

Questions on Drilling-machine Accessories

1. What is a drill chuck? What kind of shank has it? Why is the shank provided with a tang?

2. What kind of drills are held in a drill chuck? What kind of drills are not held in a chuck? Why not?

3. What is the difference between a drill press socket and a taper sleeve?

4. If the taper shank of the drill is of a smaller size than the hole in the spindle, how is the drill held?

5. What is a drift or key used for? How is it used? What is the objection to using a drift up side down?

6. Which holds best, an oily taper or a dry taper?

7. Is the hold of the taper alone sufficient to keep the drill from turning in the socket? Is the tang sufficiently strong to keep the drill from turning?

8. What faults in the setting of the drill might result in the tang being twisted off?

9. Why are the smaller size drills made with straight shanks?

10. Define drilling, reaming, boring and spot facing.

11. What is the difference between counterboring and countersinking?

12. If the taper shank of the chuck is too small for the spindle hole, what do you use? In any case how do you make sure the chuck is securely held in the spindle?

21. Sharpening a Drill (Fig. 23).—The clearance angle on a drill is about 12° at the cutting edge. If correctly sharpened,

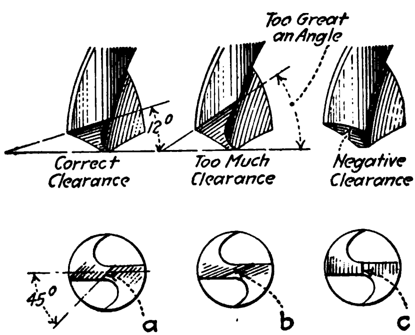
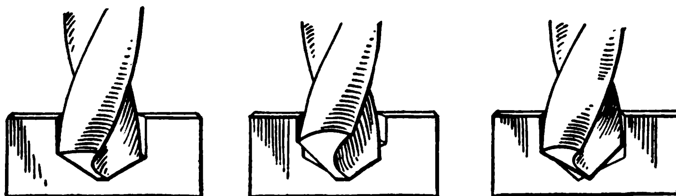


FIG. 23.

the edge of the angle across the web of the drill (the cutting point of the drill) will be about 45° with the line of the cutting edges (see *a* Fig. 23). The appearance of the cutting point is therefore an index to the clearance; when it is like *b* the lip has too much clearance and when it is like *c* the lip has no clearance. It is very important that a drill should have sufficient lip clearance as it takes considerable pressure to feed the drill into the work under the best possible conditions,

owing to the nature of the point, and if the lips are not properly backed off the drill will break under feeding pressure simply because it cannot cut.

Extreme care must be taken to get the lips exactly the same



(a) (b) (c)

FIG. 24.—(a) Lips of different lengths; drill will cut oversize. (b) Lips with different angles with axis of drill; drill will wobble and cut oversize. (c) Lips with different inclinations. One lip does practically all the work which tends to crowd the drill toward the opposite side and wear off the land.

length and both at the same angle with the axis of the drill or the hole will be oversize. This is illustrated in Fig. 24.

Theoretically if the drill is ground at an angle of 59° with the axis, the best results will be obtained. Therefore the drill should be held at about 59° or 60° with the face of the grinding wheel (see Fig. 25). The observant student will soon learn to notice any inequality in the lengths of the lips or in their angles with the axis of the drill.

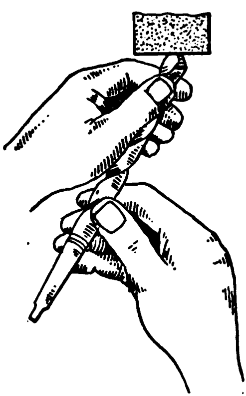


FIG. 25.

When sharpening the drill hold the drill as shown in Fig. 25. Place the left hand on the rest, with the right hand slightly lower than the left hand, and the cutting edge of the drill *up* and in a *horizontal* position. As the right hand is lowered the drill fulcrums in the left hand, and with the necessary pressure against the wheel the required clearance is obtained.

To strengthen a drill the web is made thicker toward the shank. This is not noticeable on drills under ¾″ diameter

but on larger sizes, as the drill is shortened, it becomes necessary to grind the point somewhat thinner as shown in Fig. 26. Use a narrow grinding wheel and be careful to preserve the center by grinding an equal amount from each side, and not to weaken the web unnecessarily by thinning too far back.

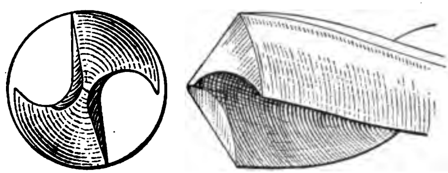


FIG. 26.—Thinning the point of a drill.

It often happens through ignorance or carelessness that a drill is used after it becomes dull, which causes the land to become worn away for a distance back from the cutting edge. The diameter of the end of the drill is reduced, thus making the drill bind and squeak. It will be necessary to grind off the damaged end and then sharpen the drill. *Always examine a drill before using it.*

22. Drill-grinding Machine (Fig. 27).—In shops where any considerable amount of drilling is done it is economical to have a drill-grinding machine. This machine may be quickly adjusted to support a drill of any length or diameter in a wide

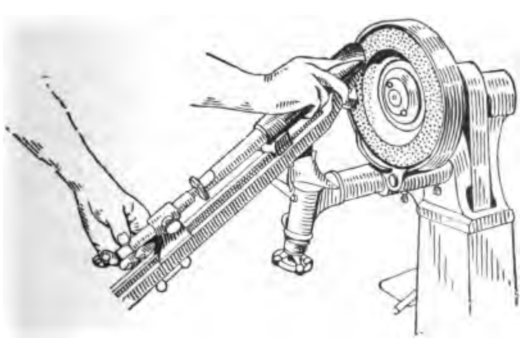


FIG. 27.—Drill grinder.

range of sizes and is so designed that it is a very simple matter to grind the drill properly, that is, with the lips of equal length, at the correct angle with the axis, and with the correct clearance. However, there are many times when it is advisable

and even necessary to grind a drill by hand, and every *real* machinist knows how to do it correctly and quickly.

23. Speeds and Feeds of Twist Drills.—Owing to the variations of the hardness and toughness of the materials used in machine shop practice, no hard and fast rule can be given for the speeds and feeds of twist drills.

The correct speeds and feeds must be determined by the judgment of the operator, and the following hints will help the beginner to obtain this necessary knowledge.

When the cutting edge breaks off the feed is too heavy, or the drill has been given too much clearance (see Fig. *b*, 23).

When the drill splits, there is too much feed or the drill has not been given enough clearance. *There seems to be a tendency for the beginner to give insufficient lip clearance toward the center of the drill. The whole length of the lip must be backed off or the drill will surely break under the feeding pressure.*

The rapid dulling of the drill especially at the outer ends of the lips (the corners) is evidence of too much speed.

When a drill squeaks it is usually an indication of a crooked hole or dullness. Never allow a drill to squeak.

The following tables of speeds and feeds are here given as having proved practical for average conditions:

Speeds of Carbon-steel Drills (Average)

20′ to 25′ per minute for annealed carbon steel.
30′ to 35′ per minute for soft steel or cast iron.
60′ to 100′ per minute for brass.
These speeds may be *doubled or more* for high-speed drills.

Note.—To obtain the number of revolutions necessary to give the proper cutting speed, divide one-quarter of the diameter of the drill into the cutting speed desired.

Feeds for Drills (Average)

.004″ per revolution for drills ¼″ or smaller to .015″ per revolution for drills 1½″ and larger.
Same feeds per revolution for high-speed drills.

24. The Use of Cutting Compounds.—It is a well-known fact that the use of some sort of cutting compound when machining

steel makes for better work and longer life of the cutting tool. It is true that in ordinary lathe turning and shaper and planer work cutting compound is not used because the advantages to be obtained from using enough oil do not compensate for the disadvantage of having the oil over everything. In drilling-machine work, however, it is necessary to use a lubricant in order not to tear the surface of the holes drilled or reamed or tapped, and also not to ruin the cutting tool. Remember, however, that no lubricant is used when machining cast iron.

FIG. 28.—High speed upright drilling machine with direct motor drive. Has compound table. Has arrangements for using cutting lubricant. (*Courtesy Cincinnati-Bickford Tool Co.*)

In Fig. 28 is illustrated a drill press provided with means of conveying cutting lubricant to the work, and also with another excellent feature, a table and base designed to keep the oil off the floor.

Cutting Lubricants Used in Drilling, Reaming and Tapping

Carbon Steel.—Lard oil or a reliable commercial cutting compound.

Soft Steel or Wrought Iron.—Lard oil or soda water, or cutting compound.

"*Unannealed*" *steel* and *hard spots in cast iron.*—Turpentine.

Malleable Iron.—Soda water.

Aluminum, Copper and *Other Soft Alloys.*—Kerosene.

Brass.—Dry, or a flood of paraffine oil.

Cast Iron.—Dry, never use any cutting compound when drilling cast iron.

25. Oil-tube Drills.—When manufacturing quantities of steel parts in which it is required to have holes ½″ or more in diameter drilled fairly deep it has often proved economical to use drills with oil tubes (or holes) running lengthwise spirally through the body to carry the oil directly to the cutting lips. Such a drill with the necessary oil-feeding socket is illustrated in Fig. 29. The oil is carried from the reservoir (any suitable can or pail set fairly high to give sufficient pressure and provided with a stop cock will do) through a pipe to the tube on

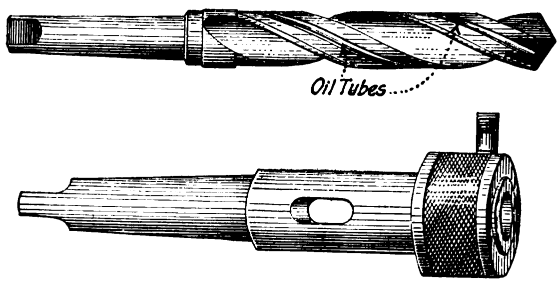


FIG. 29.—Oil tube drill and oil feeding socket. (*Cleveland Twist Drill Co.*)

the side of the collar. The collar may be held from turning with the socket by using a piece of ¼″ gas pipe long enough to reach the column of the machine or other suitable stop. The collar and also the body of the socket are provided with channels through which the oil is forced into the holes in the shank of the drill, which register with the channels, and thence through the tubes in the drill to the cutting edges.

Questions on Drills and Drill Grinding

1. How is the drill held when grinding by hand, is it placed on the hand rest, or held in the hand? Why?

2. How is the drill grasped with the right hand?

3. What angle does the center line of the drill as properly held make with the face of the grinding wheel? Why not 45°? Why not 30°?

4. Why is the drill held with the cutting edge up and in a horizontal position?

5. How is the drill moved against the wheel to "back off" the cutting edge? Why not give it a twisting motion?

6. What do you mean by fulcruming the drill in the left hand?

7. Why must care be taken to have plenty of water available when grinding a drill?

8. If a properly ground drill is held perpendicular to a flat surface, what angle will one of the cutting edges make with the surface?

9. How much clearance has the cutting edge of the drill?

10. What part of the twist drill is the lip? The point? The land?

11. What is the effect of too much lip clearance? Of not enough lip clearance?

12. How can you tell by looking at the point of a drill whether or not the drill has been given sufficient lip clearance?

13. Has the drill any other clearance?

14. What is "rake" on any cutting tool?

15. What governs the amount of rake on a twist drill?

16. Why cannot a set rule be given for the speeds and feeds of drills?

17. What does the squeak of a drill indicate?

18. What do you mean by the land of the drill being worn away? What causes this? How do you repair the drill?

19. How many revolutions per minute should a ¾" drill be run to give a cutting speed of 35 feet per minute?

20. State two advantages of the spiral flute.

21. On what kinds of work is a straight fluted drill used?

22. How may a twist drill be ground to have the effect of a straight fluted drill?

23. State two advantages of using a cutting compound when drilling steel.

24. When is turpentine used as a cutting lubricant?

25. What is the advantage of an oil tube drill? When is it used?

26. State how you would make a flat drill 1½" in diameter.

27. What is the purpose of thinning the point of a drill?

28. What care should be taken when thinning the point?

HOLDING THE WORK

26. Drill Jigs (Fig. 30).—In most commercial drilling the work is held in a jig. A jig is an especially made device for holding work and guiding the cutting tool while drilling (and often while machine reaming and tapping). It has hardened steel bushings, through which the drill is guided so that the holes are accurately located in the work.

The double bushing or "slip bushing" (*c*, Fig. 31), is provided when the jig is used for reaming and the "loose" bushing may be removed from the "fixed" or "tight" bushing to permit of entering the reamer. Sometimes a second loose bushing is provided to guide the reamer.

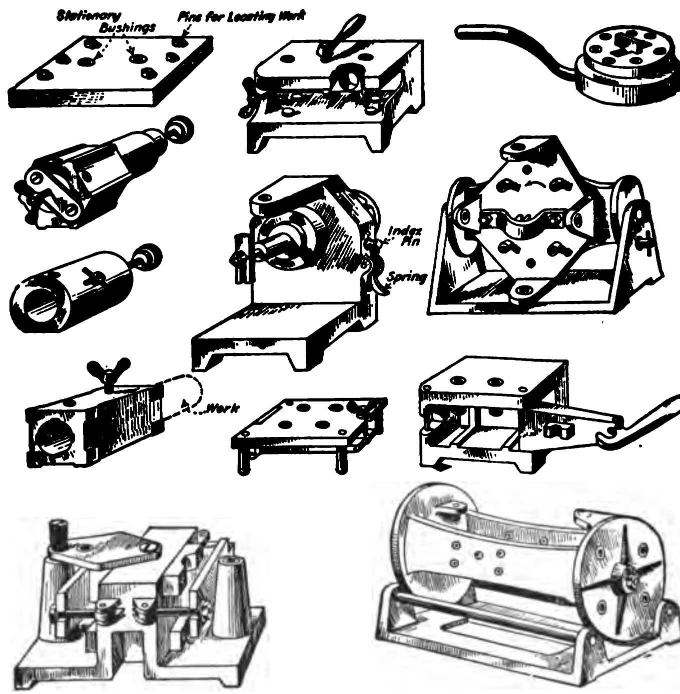


FIG. 30.—Examples of drill jigs. (*Courtesy, Publishers,* HALSEY'S "Methods of Machine Work.")

Jigs vary in cost from a few cents to hundreds of dollars depending on the number and location of the holes, the accuracy required, and the size of the jig. The jig is used in manufacturing numbers of duplicate pieces. It is one of the most important of the rapid production tools in that it saves the time of laying out and also the extra expense of drilling to a layout.

Where two or more different sizes of holes are to be drilled it is customary to set up a gang drill (see Fig. 5) or even several machines with the drills or other cutting tools in proper sequence in the respective spindles, and pass the jig from one spindle to the next.

Generally speaking it calls for rather more intelligence and skill to set up the job in a vise or on the table, and drill the holes to layout, than is involved in the use of a jig, consequently it is more interesting. It is important that every machinist shall be able to lay out and set up the work and drill the holes

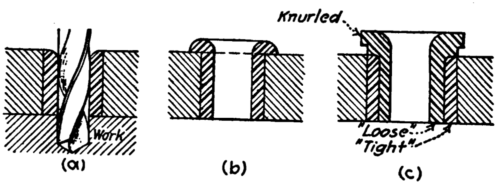


FIG. 31.—Types of jig bushings. (*a*) Flush bushing, (*b*) Flanged bushing, (*c*) Slip bushing.

accurately without the use of a jig. An example of laying out and a few hints on setting up the work follow.

27. Laying Out for Drilling.—The process of laying out work for drilling consists of indicating by means of intersecting lines the positions of the centers of the holes to be drilled. At the point of intersection a slight prick punch mark is made, and using this as a center a circle indicating the size of the hole is scribed with a divider. If the surface on which the layout is to be made has been machined a coating of blue vitriol solution may be applied and allowed a moment to dry. The lines scribed on this surface will show very distinctly. Chalk rubbed well into the unfinished surface of a casting will serve the same purpose. A simple example is here given to illustrate two methods of laying out.

28. Example of Laying Out.—Lay out and drill four $\frac{5}{8}''$ holes, symmetrically located, in the face of an angle plate as per dimensions given in the sketch (Fig. 32).

1. Measure the width of the plate, subtract 3″ and divide by 2 to obtain the distance *a*.

2. Place the angle plate on a suitable parallel on a surface plate and with the surface gage scriber set the distance *a* above the parallel, scribe the line *AB*.

3. Measure the height of the angle plate subtract 5″ and divide by 2 to obtain the distance *b*.

4. Adjusting the surface gage to the distance *b* above the parallel and placing the angle plate on surface *S*, square up line *AB* if necessary and scribe line *CD*.

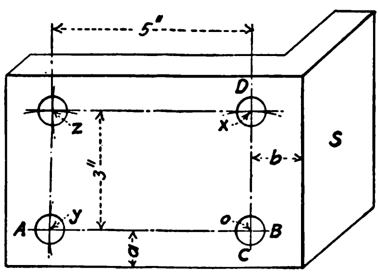


Fig. 32.

5. The point of intersection of the lines *AB* and *CD* is the center *O* of one hole. Make a slight indentation at this point with a prick punch.

6. Set a divider to 3″ and on *O* as a center scribe an arc intersecting the line *CD* at *x*. Make a slight prick punch mark at *x*. This is the center of the second hole.

7. Set the divider to 5″ and with *O* as a center scribe an arc intersecting the line *AB* at *y* and with *x* as a center and the same divider setting scribe a fairly long arc at *z*. Make a prick punch mark at the intersection of the arc at *y* and the line *CD*. This is the center of the third hole.

8. Carefully set the divider to 3″ once more and with *y* as a center scribe another arc at *z* intersecting the arc already scribed. Make a prick punch mark at the intersection of these two arcs. This is the center of the fourth hole.

9. Set the divider to $\frac{5}{16}$″ and with *o*, *x*, *y*, and *z* as centers scribe the $\frac{5}{8}$″ diameter circles to indicate the positions of the four holes.

Another method of finding the centers of the four holes is as follows: After line *AB* is drawn, set the scriber of the surface gage 3″ higher and draw line through *zx* and after line *CD* is drawn set the scriber 5″ higher and draw line through

yz. Which method is more practicable depends upon the location of the holes and the size of the work and the available tools. The given example serves merely to illustrate the methods.

Whoever drills these holes will make larger indentations at the centers with a center punch. By the time the job reaches him, the circles may have become more or less obliterated and the re-scribing should be done from a *prick punch mark* rather than from a *center punch mark*.

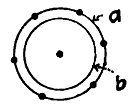


FIG. 33.

When the surface on which the layout is to be made is *unfinished*, for example, cast iron without the scale removed, a series of half a dozen or more center punch marks around the circle will serve to make the layout plainer (see *a*, Fig. 33). It is a good plan for the beginner when laying out holes he is to drill to scribe also from each center a circle somewhat smaller than the finished size of the hole to help in gaging the central position of the spot made before the drill cuts its full diameter (see *b*, Fig. 33).

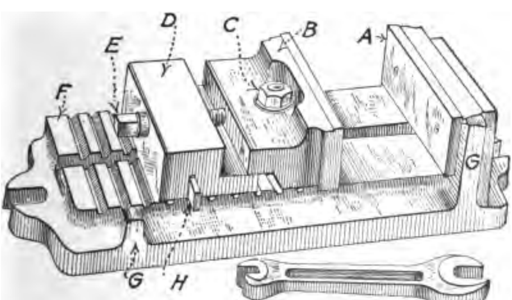


FIG 34.—Drill press vise. (*Skinner Chuck Co.*)

A, solid jaw; *B*, movable jaw; *D*, backing block. To clamp work move *B* close to work and tighten *C* but not too tight. Bring backing block *D* as close to *B* as will permit strip *H* to settle in nearest groove milled across the face *F* of the base. Tighten *E* and then tighten *C* this time securely. The faces *G* are finished square with the bottom to permit of using the edge of the vise as a seat if so desired.

29. The Use of Clamps and Stops.—All drill-press work, except the extra heavy pieces, should be located against a stop or clamped to the table. When a vise, (Fig. 34), is used to hold

the work, the vise should be clamped to the table or located against a stop. A jig should be located against a stop. *Never under any conditions should a piece of work be held by hand against the force of a revolving drill or other cutting tool.*

The work table is provided with enough T-slots to enable the

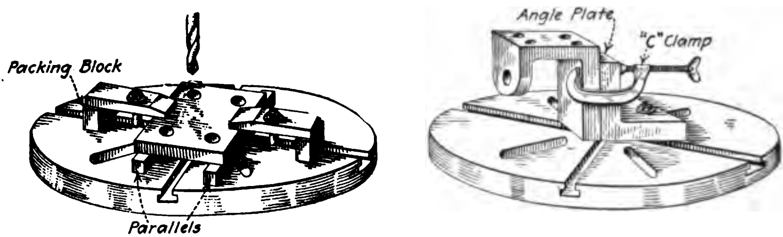


FIG. 35.—Holding work on drill press table.

operator to locate conveniently the necessary bolts for the stops or clamps.

Figure 35 shows methods of clamping work for drilling that are self-explanatory. Figure 36 illustrates a cylindrical piece held in V-blocks and also the method of arranging the center punch mark exactly over the axis of the cylinder or "central."

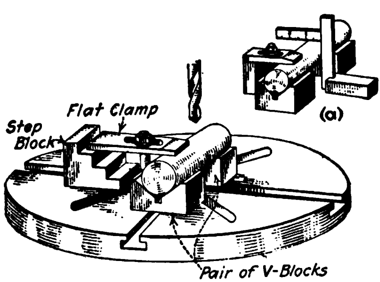


FIG. 36.—If a cylindrical piece is not too large it may be clamped in a vise; if this is inconvenient it may be clamped as shown. In either case, when setting up have the work clamped lightly with the center punch mark as nearly over the axis of the cylinder as may be judged by eye. Then, holding a square on the table and against the cylinder, roll the work until the measurement between the blade of the square and the center punch mark equals one-half the diameter of the work. Finally, tighten securely.

Have the bolts as near the work as practicable and securely fastened. That part of the work upon which the clamp is

placed should be rigidly supported to avoid springing under the clamping pressure. If the work does not itself bear on the table at the clamping point, it should be shimmed or blocked under this point.

NOTE.—Certain principles of clamping work are explained in Chapter VII. It is suggested that the student refer to these explanations.

It is not always necessary to use clamps, as a matter of fact a stop is nearly always sufficient. It is usually better to allow the work to move a little, as it is then easier and quicker to align the center punch mark with the drill point and there is less likelihood of inaccurate alignment. This is especially true when the spot has been gouged with the chisel (see paragraph **30**).

If the work is fairly high on a small base and the stop low, the force of revolving drill tends to tip the work thus straining the drill and possibly spoiling the hole. If convenient use two stops, opposite, locating the second stop after the spot is made. If only one stop can be used, have it high enough to counteract the tendency to tip. After the hole is well started it may be best to clamp the work.

A Very Important Precaution.—When setting up for drilling holes through the work make sure that the work is so arranged as to permit the drill to go through without drilling into the vise or the table or the parallels.

Questions on Holding Work

1. Examine the table of the drill press. Have several holes been drilled into the table top? Examine a drill vise. Has the drill been allowed to go through the work into the vise? Is carefulness or carelessness indicated?

2. What is the first care when setting up a drilling job?

3. Why is a stop usually sufficient for holding a vise? Why is it better for most work than a clamp?

4. Why is it necessary to use either a stop or a clamp?

5. Do the same principles apply to pieces not held in a vise?

6. If the work is fairly high, how are the stops arranged? Why two stops?

7. On what shape of work is the V-block a convenient holding device? What angle with each other are the sides of a V-block?

8. How is the V-block secured to the table? How is the work held in the V-block?

9. When is an angle iron a convenient tool for holding work? How is it fastened to the work table?

10. How is the work fastened to the angle iron?

11. What is a C-clamp?

12. What care must be taken when applying a clamp?

13. Certain pieces are often supported by parallels and then clamped? What are parallels? Why are parallels used?

14. What is the advantage of a T-head bolt?

15. When clamping a piece of work why should the bolt be placed near the work?

16. Why is a packing block used under the clamp? How high should it be? Why?

17. What is a U-clamp? What advantages has it?

18. What is a pin clamp (finger clamp) used for?

19. What do you mean by "shimming" a piece of work? What is the difference between blocking and shimming?

20. Why must the work be solid under the clamp? If the part where the clamp is applied overhangs, what must be done before clamping?

21. What are the objections to springing the work when drilling? How may it be avoided?

22. Make a sketch of a piece properly clamped showing the work, the bolt, the clamp, and the packing block.

23. What is the use of a washer? Should a nut ever be used without a washer? Give reasons.

24. How far should a nut be screwed on a bolt? Give reasons.

25. What are the advantages of a jig?

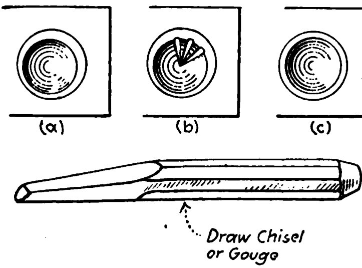
26. In your opinion when is it profitable to make a jig?

27. For what reasons, do you think, it is more expensive to drill to a layout than to use a jig?

30. Drilling the Hole.—Align the point of the drill carefully with the center-punch mark, start the machine and make a spot half or two-thirds the diameter of the drill. Back the drill away from the work and note if the spot is central with the scribed circle. If not central, *a*, (Fig. 37), chip one or more shallow grooves *b* on the heavy side. A drill will go toward the least resistance and chipping away stock on the heavy side will tend to make the drill cut toward that side. This

operation may have to be repeated. Watch carefully and be sure the spot is central before it is the full diameter of the drill, *c*, (Fig. 37).

When a drill is properly ground, and operated at the correct speed and feed, the chips should appear as illustrated in Fig. 38. As the hole becomes deeper the chips break up more or less while being forced out. When the depth of the hole is several times the diameter of the drill, the removal of the chips becomes more difficult and it is often advisable to slightly increase the feed and decrease the speed as this gives a greater freedom of chip movement. Sometimes it is necessary to remove the drill from the hole to clean the chips (and if drilling steel to apply the cutting compound). A magnetized file is very useful for removing chips from the hole.



Fig' 37.—Shows use of gouge to draw the spot to center.

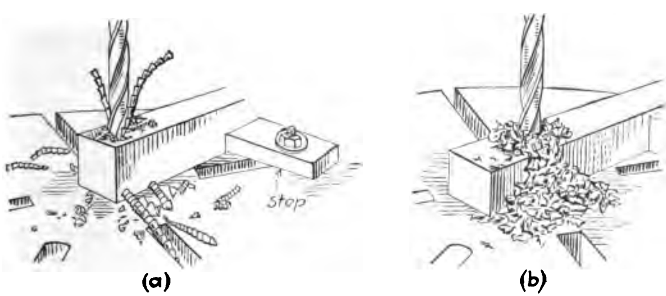


Fig. 38.—Shows appearance (*a*) of steel chips and (*b*) of cast iron chips when properly sharpened drill is used.

If, when drilling steel, the drill is removed from the hole *great care must be taken when the drill is re-entered that a chip is not lodged between the point of the drill and the bottom of the hole.* When this happens the drill will ride on the chip, and if the feed is thrown in, the machine will be subjected to an

enormous over-strain, and, if continued, either the machine or the drill will be broken Always start the feed by hand, make sure the drill is cutting, then throw in the power feed.

When all conditions are right a fairly deep hole may be drilled straight. If, however, a hard spot or a blowhole is encountered, or if the work is not properly seated or held, or if the drill is improperly ground or dull, the hole is likely to "run." One can usually tell when a drill or other cutting tool is not acting properly by the "feel" or by the sound, or by the appearance of the chip.

31. Using a Piece Already Drilled as a Template.—When several flat pieces have to be drilled it is frequently practical to lay out and drill the first piece and then use it as a template

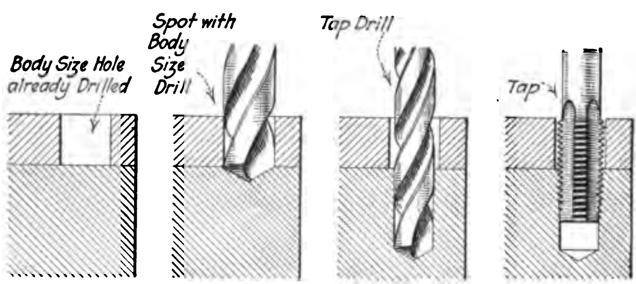


FIG. 39.—Spotting and drilling for tap.

when drilling the others. The pieces should be held together in some manner in order that either piece does not slip. They may be clamped together, or both clamped to the table, or held between the vise jaws, or located against suitable stops; as long as the drilled holes are in the same relative positions in the pieces drilled any way of holding the pieces that is convenient will answer. If two or more holes are to be drilled in each piece it will be a good plan after the first hole in the bottom piece is drilled to slip a suitable plug through both the top and bottom pieces to tie them together while the other holes are being drilled.

Very often in machine construction when one part is fastened to another part by screws it is advisable to "spot"

through the body size holes drilled in one to locate the positions of the tap size holes[1] in the other. This operation is illustrated in Fig. 39. If several holes are to be spotted and drilled it will be best to tap the first hole as soon as it is drilled —possibly the first two holes and hold the pieces together while the other holes are spotted and drilled.

32. Drilling Large Holes.—The larger the drill the greater the thickness of the "web" between the flutes and consequently the wider the "point." The point of the drill has a very ineffective scraping action rather than a keen cutting action and to feed efficiently a drill say 1½″ diameter in a 20″ drill press will unduly strain the machine. In such a case it will save time and trouble to thin the point of the drill as described on page 25.

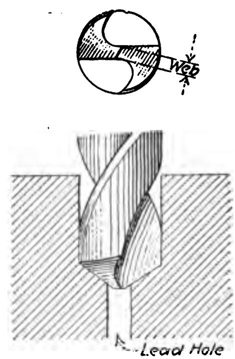


FIG. 40.—Following a lead hole or pilot hole.

Some machinists prefer to drill a lead hole (Fig. 40) of a diameter equal to about the thickness of the web of the larger drill. It is very necessary to drill this hole accurately to layout because the larger drill will surely follow the small hole. Do not drill a lead hole much larger than necessary or the following drill may chatter and drill out of round or at least spoil the "mouth" (top) of the hole. In any event do not crowd the drill, that is, feed it too fast, when starting.

33. Tap Size Drills.—The diameter of the hole to be drilled for the threads in a nut or any inside threaded piece is theoretically the root diameter of the corresponding screw size. This size of hole will give a *full thread* which is required in a die and occasionally in a special piece, but it is *not practical* or *customary* to tap a full thread, therefore the *tap drill sizes* are usually larger than the root diameter.

Two-thirds of the double depth of thread is enough to leave

[1] For information concerning tap size drills see paragraph 33. For tables of sizes see List of Tables, p. 397.

for tapping (See Fig. 41). An ordinary nut so drilled that it has only half of a full depth of thread will break the bolt before it will strip. A two-thirds depth of thread will give a margin of safety of about 2:1 and only requires about one-third the power for tapping that is required to tap a full thread. As explained in paragraph **148**, Part I, the full double depth of a U. S. Std. thread is obtained by dividing 1.299 by the number of threads per inch. Consequently, dividing ⅔ of 1.299 by the number of threads per inch will give two-thirds of the full depth of thread (⅔ of 1.299 = .866 or approximately .9).

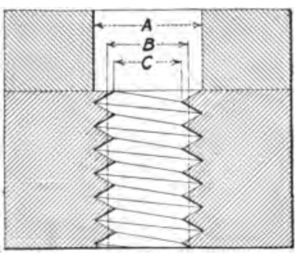


Fig. 41.—*A* is body size; *C* is root diameter; *B* is tap drill size that will leave enough stock for about two-thirds of a full thread as shown.

Therefore in ordinary machine work, if a list of tap-drill sizes is not at hand, the size of a hole to be drilled for tapping (U. S. Std. form of thread) may be found by subtracting from the outside diameter of the tap, the quotient obtained by dividing .9 by the number of threads per inch. Select the size of drill required or the nearest 64th under for taps over ¼″ and the nearest number size drill for taps ¼″ and under.

Example.—½ tap—13 threads.

Solution.—.500 − .9 ÷ 13 = .500 − .069 = .431″. The nearest drill under .431″ is 27/64″ (.421″).

34. Hints on Drilling.—Examine the job or the blue print or both to determine the necessary tools, bolts, clamps, etc. to use. Get these things together without making any extra trips to the tool-room and elsewhere.

Be particular to have the taper hole and the taper shank *clean and dry*, and the cutting tool securely held.

When the drill "breaks through" at the end of the cut it has a tendency to "dig in" especially when drilling thin pieces and also when drilling through a cylinder at right angles to the axis or into another hole at right angles. Such pieces should be clamped down and when hand feed is used extreme

care must be taken or a broken drill will result. The tendency to dig in is greatly increased by lost motion in the thrust bearing between the sleeve and spindle.

When drilling small pieces, and thin pieces especially, it is often more convenient to place them on a suitable piece of board. Set the depth gage to allow the drill to go through the piece but not through the board. Such pieces may be stopped from turning by a nail driven in the board or they may be held in a wrench.

A squeak indicates undue friction. The cause should be looked for immediately and the fault corrected. Occasionally when drilling cast iron it is advisable to rub a little oil or tallow on the *lands* of the drill.

When a machine is overworked it will "groan." A dull cutting tool, a chip under the cutting edge, a lack of lip clearance and over feeding are frequent causes. Throw out the feed at once and proceed to find and correct the fault.

Read carefully on page 26 the causes of spoiled work and broken drills due to faulty grinding.

Questions on Drilling

1. Is the drill properly sharpened? Have the cutting edges been given sufficient clearance?

2. If the hole is to be drilled through the piece, what precaution must be taken?

3. If the hole does not go through the piece, how may the depth be gaged on the spindle?

4. Is the "depth" of a drilled hole measured from the point or from the corner? Ans. From the corner.

5. When, in general, is it necessary to use a clamp to hold the work? When is it better to use a stop? Why is it nearly always best to use one or the other? When may it be unnecessary?

6. How is a straight shank drill held?

7. How is a taper shank drill held? Why should the taper be clean and free from oil? How is the drill removed?

8. What is the difference between a prick punch mark and a center-punch mark? When is each used?

9. When is chalk or whiting used in a layout? When is blue vitriol solution used in the layout?

10. Why are prick punch marks sometimes made in the circles showing size and position of holes?

11. If two or more holes are to be drilled in a piece securely clamped to the table, how may they be located in turn under the drill without loosening the clamps?

12. What is meant by spotting a hole with a drill? How large a spot should be made?

13. If the center punch mark in the layout is practically true, why will not the drill always start true and cut true?

14. If the spot shows out of center with the layout, a gouge chisel should be used. On which side of the spot is it used? How many chisel cuts should be made? How deep?

15. If a piece is clamped to the table before it is located exactly under the drill, is it necessary to adjust the table before drilling the hole if a draw chisel is used? Give reason?

16. How may chips be removed from a hole?

17. Is a lubricant used when drilling cast iron?

18. Does a squeak indicate proper or improper conditions? Why?

19. If a fairly deep hole is being drilled in cast iron how may oil be used?

20. It is sometimes necessary to remove the drill from a partly finished hole. If a steel chip lies under the point of the drill when it is run back in the hole, what is the result? What is the remedy?

21. When does a machine "groan?"

22. Why is it best to always feed by hand until you are sure the drill is cutting?

23. If no chip is under the drill and the machine groans what is indicated?

24. What is indicated when the extreme outer corners of the cutting edges of the drill wear away rapidly? What will happen if this fault is not immediately corrected?

25. Either one of two faults may cause the lips to chip. What are these two faults?

26. A very common fault in grinding causes a drill to split up the web; what is it?

27. How is the proper cutting speed of a drill determined?

28. How many revolutions per minute are necessary to cut 30 feet per minute with a 7/8" drill? To cut 40 feet?

29. How many revolutions per minute are necessary to cut 40 feet per minute with a drill 1 1/4" in diameter?

30. How many revolutions per minute are necessary to cut 35 feet per minute with a 1/4" drill?

31. What lubricant is used when drilling soft steel or wrought iron? When drilling unannealed steel? When drilling aluminum?

32. How does lost motion in the spindle thrust bearing account for breakage of drills?

33. How is a twist drill ground for drilling brass? Why?

34. What is meant by thinning the point of a drill? When is it advisable?

35. When is it advisable to use a pilot drill?

36. What is the difference between a jig and a template?

37. Explain the advantage of using as a template, a piece which has been correctly laid out and drilled.

38. When and how may a piece which has been drilled be used to "spot" holes in another part.

39. State three things, any one of which will prove that a drill or other cutting tool is not "working right."

40. State at least four things the knowledge of which make for efficiency in drill press work.

CHAPTER III

OTHER DRILL PRESS TOOLS AND OPERATIONS

REAMERS

It is practically impossible to drill a hole to the exact size of the drill. Therefore to obtain a hole of standard size, round and smooth, it is practical to drill or bore to $\frac{1}{32}''$ undersize and then machine ream. If extreme accuracy is required, it may be machine reamed or bored to within .002″ to .004″ of size and then hand reamed.

35. Chucking or Machine Reamers (Fig. 42).—Machine reamers are much used in drill presses, lathes and similar

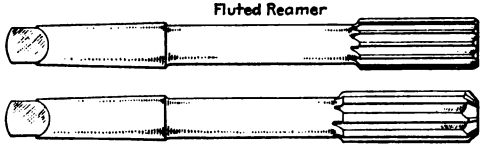


FIG. 42.—Machine reamers.

machines. There are two types of machine reamers, rose reamers and fluted reamers.

In the *rose reamer*, the teeth are beveled on the end and "backed-off"; they cut only on the end. The lands[1] are nearly as wide as the grooves and are not relieved (backed-off). The flutes or grooves are provided for conveying oil to the cut and chips away from the cut. The rose reamer tapers slightly smaller toward the shank (about .001″) to prevent binding. It does not cut a particularly smooth hole but is very useful to bring the hole to within a few thousandths of size when it may be finished with the hand reamer. Rose reamers, therefore, are usually made .002″ to .004″ under nominal size.

[1] *Land.*—In reamers, milling cutters, etc., the width of the top of the tooth is called the land.

The *fluted reamer* has more teeth for a given diameter than the rose reamer. The lands are narrower, and are backed-off the whole length. The front ends of the teeth are beveled or rounded and then relieved. It is a valuable finishing reamer when extreme accuracy is not required.

Both the rose reamer and the fluted reamer are made with either straight or taper shanks. It is not usually advisable, on account of the extra cost, to buy taper shank reamers under $7/16''$ diameter; and it is not usually good practice to buy straight shank reamers of over 1″ in diameter on account of the difficulty in holding them.

36. Shell Reamers.—For reasons of economy, many manufacturers prefer the shell reamers and arbors illustrated in Fig. 43. These reamers are made in either rose reamer style or fluted reamer style and the arbors with either straight or taper shanks, and differ in no particular respect from the

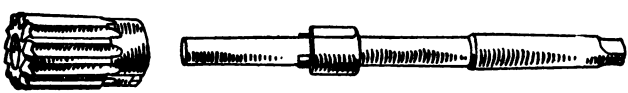


FIG. 43.—Shell reamer and arbor.

ordinary solid reamer except that one arbor may be fitted to a number of reamers and when a reamer is worn out it may be thrown away without discarding the arbor, making for economy in the end.

37. Hand Reamers (Fig. 44).—Where a particularly accurate hole is required it is first drilled or bored or machine

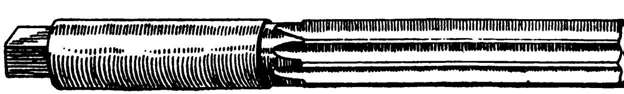
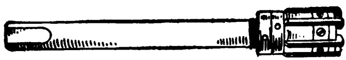


FIG. 44.—Hand reamer.

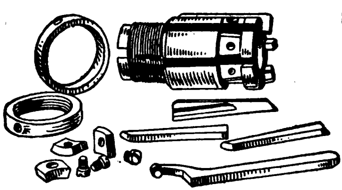
reamed .002″ to .004″ undersize and then hand reamed. *Do not leave over .005″ for a hand reamer.*

A hand reamer is essentially a finishing tool, a scraping tool. It is ground straight for nearly the whole length of the teeth,

being slightly tapered, smaller toward the end, for a distance about equal to its diameter, to permit of its entering the hole to be reamed. This slight taper also serves to give the scraping action which produces the smoothness of the hand reamed hole. The teeth are relieved a very little for clearance. The shank end is machined square to receive the wrench (Tap wrench, Fig. 53). *The hand reamer should never be operated by mechanical power.* Care should be taken to start it true and keep it straight. It is often advisable to start the hand reamer when aligned and steadied by the dead center of the lathe or a center placed in the drill press spindle as the case may be. The drill press center should have a tang in order that it may be removed with a drift.



Adjustable Reamer (Solid)



Adjustable Reamer (Shell)

FIG. 45.

38. Adjustable Reamers (Fig. 45).—This type of reamer can be adjusted to sizes within a considerable range over or under its nominal diameter; often a valuable feature. While the first cost of reamers with adjustable blades is considerably in excess of the solid type of reamer, the fact that they may be easily sharpened and quickly adjusted to an exact size, and their corresponding long life, makes them a particularly efficient tool. These reamers are made in all standard sizes, either hand or machine, with the body and shank in one piece or of the shell reamer variety.

39. Taper Reamers (Fig. 46).—Hand taper reamers, both for roughing and finishing, are made for all of the standard sizes of tapers. The end of the shank is cut square to receive the wrench and the reamer should always be turned by hand. Most taper reaming is done by hand because of the great likelihood of breaking the reamer under the stress of mechanical power. However, if the reamer is provided with a *taper shank* large enough and properly fitted, and if great care is taken to feed *very* slowly, taper reaming, especially rough-

ing, is accomplished easier and probably quicker in the machine than it can be by hand. As the chips do not fall out readily a taper reamer when operated either by hand or power should be removed often and cleaned.

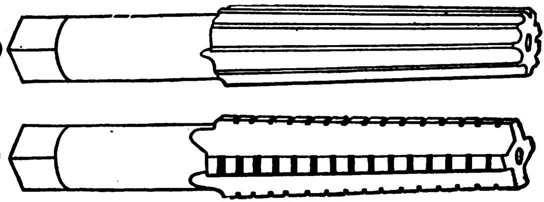


FIG. 46.—Taper reamers (*a*) finishing; (*b*) roughing.

40. Chattering.—To avoid the tendency to chatter the reamer should be in line with the hole and then carefully fed at the start, preferably by hand. To lessen the likelihood of chattering reamers are *increment* cut, that is, the teeth are unequally spaced; the faces of the teeth are radial or slightly ahead of radial to give a scraping cut, and the lands are relieved only a small amount.

NOTE.—For fluting reamers increment cut see p. 261.

To further lessen the tendency to chatter, the teeth of reamers, especially power driven taper reamers, may be cut on a spiral. In the case of a spiral cut reamer, the spiral should be left-hand, that is, the twist should be opposite that of a twist drill, otherwise the tendency is for the reamer to pull into the hole and this would tend to increase rather than to diminish the chatter.

41. High-speed Reamers.—Cutting tools made of high-speed steel will cut at least twice as fast and often four or five times as fast as similar tools made of carbon steel. It follows that where it is practicable to obtain the increased speed, it is profitable to use high-speed cutting tools. For example, in production work where considerable machine reaming is to be done, it is economy to use high-speed reamers. An adjustable machine reamer with high-speed steel blades is very efficient since it has the advantage of the tough steel body,

and the high-speed steel blade. It is, however, rather expensive and to overcome this objection one manufacturer (Cleveland Twist Drill Co.) has developed a reamer with high-speed blades welded to a body of tough alloy steel.

42. The Operation of Reaming.—It depends upon the degree of accuracy and finish desired whether or not a hole should be reamed at all and also whether it should be merely machine reamed or finished with a hand reamer. For example, bolt holes or cap screw holes, whether body size or tap drill size are not reamed, while holes for dowel pins, pivot pins, hinge pins, etc. must be reamed. Further, a hole into which a mandrel is to be used for other machine operations, for instance, the hole in a pulley or in a gear blank, must be reamed. When the hole is fairly long in proportion to the diameter and an extra smooth surface is not required, a fluted machine reamer will give the desired result. When a high degree of accuracy and finish is desired a hole had best be hand reamed. It is first machine reamed with a fluted reamer or rose reamer .002″ to .005″ undersize which leaves the correct scraping chip for the hand reamer.

A hole that is to be reamed is drilled with a "reamer drill" which is usually $\frac{1}{64}$″ or $\frac{1}{32}$″ "undersize" (less than the finished diameter of the hole).

It is customary to immediately follow the drill with the reamer, especially if the work is clamped, to insure alignment. The speed for reaming is usually somewhat less than for drilling, to avoid any tendency to over-heat and ruin the cutting edge. The feed should not be crowded or the reamer may tear the surface of the hole. Be sure the reamer runs true and take care in starting the cut, otherwise a chatter may develop which will spoil the mouth of the hole. If the reamer chatters, stop the machine and then start very slowly, pulling the belt by hand if convenient.

If the hole is to be hand reamed it may be well to put a center in the drill press spindle to align and steady the reamer until it is well started. As the reamer is turned with a tap wrench and cuts its way into the hole follow it up with the

center but do not crowd it; feed by hand. Assistance will probably be necessary.

When, as frequently happens, it is desired to duplicate a flat piece having two or more holes already drilled and reamed, a quick accurate method is as follows: Obtain a drill, the size of the reamed hole, to be used as a "spotting" drill, a machine reamer of the desired size, also a reamer drill $\frac{1}{64}''$ or $\frac{1}{32}''$ smaller. Clamp or otherwise arrange the two pieces with the one to be drilled and reamed in position under the piece already reamed, with the first hole aligned under the "spotting" drill in the machine spindle. Spot this hole, then remove the spotting drill and put in the reamer drill (undersize drill) and drill the hole. Then ream with the machine reamer. After reaming and before proceeding to the next hole insert any suitable pin or plug through the two pieces to keep them in exact relationship while the next hole is being spotted, drilled and reamed. If three or more holes are to be made it will be wise to use a second plug as this will prevent any shifting of either piece while the other holes are being made.

43. Hints on Reaming.—A burr on the tooth of a hand reamer will spoil the hole. When any reamer is obtained from the tool room, feel along the cutting edge or the land of each tooth and if any burr is noticed, oil-stone it off.

Always use lard oil or other suitable cutting compound when reaming steel or wrought metal.

It should be emphasized that *never under any circumstances* should a reamer be turned backward.

Oil is not used as a cutting lubricant when reaming cast iron. It is very often advisable, however, to put oil on the lands of a rose reamer to reduce the friction in the hole and prevent scoring.

Do not attempt to start a reamer on an uneven surface. The reamer as it starts tends to go towards the point of least resistance and if not started true will not ream a straight round hole.

A drill may be used as a reamer to give a good result if the

corners are slightly rounded with an oil-stone. Run at fairly high speed and feed slowly.

A small size reamer that will work well and may be easily sharpened may be very quickly made from a piece of drill rod of the size desired. Cut off to length, square the end, and round the corner somewhat. Then reduce the diameter a thousandth or two except for an eighth of an inch or so from this end, either by filing or with emery cloth. Now bevel the end 45° or more leaving about half of it, back off the rounded cutting edge a very little and harden and temper. Grind and oil-stone the flat bevelled surface, oil-stone the rounded cutting edge a trifle and the reamer is ready to use. Feed slowly as there is only one cutting edge.

Questions on Reamers and Reaming

1. It is assumed that the hole has been drilled. Select a reamer of the proper size. When is a machine reamer used as a finishing reamer?

2. If it is not to be used for finishing the hole how much undersize is it made? Why?

3. How is a taper shank reamer held in the spindle?

4. If the shank is too small to fit the spindle hole, what do you do?

5. Why is it necessary to wipe the taper clean and dry?

6. How is a straight shank reamer held?

7. What are the advantages of the taper shank reamer? Of the straight shank reamer?

8. Is it necessary to clamp or "stop" the work when using a machine reamer? Give reasons.

9. What part of the machine reamer does the cutting? Where is the tooth clearance? What other clearance has a machine reamer?

10. What is the use of the flutes in a machine reamer?

11. How much metal is usually left for a machine reamer to remove? Why not $\frac{1}{16}''$ or $\frac{1}{8}''$.

12. What is the cutting speed of a machine reamer as compared to a twist drill? How do the feeds compare?

13. When is a lubricant used in reaming?

14. What are the advantages of facing around the hole before machine reaming?

15. How should a reamer be started? If it chatters what is indicated?

16. If a machine reamer squeaks when used in cast iron what does it indicate? How may it be avoided?

17. If several holes are to be drilled or reamed through two pieces clamped together what precaution should be taken?

18. What is a machine reamer? Fluted reamer? Rose reamer?

19. What is an adjustable reamer? What are its advantages?

20. What is a shell reamer? What are its advantages?

21. How may a drill be used for a reamer if no reamer of the size is available?

22. How may a small size reamer be quickly made from a piece of drill rod?

23. What is a hand reamer? Why is part of the body ground slightly tapered?

24. Should a hand reamer be operated by mechanical power? How may it be used in the drill press?

25. When using a hand reamer in a drill press or lathe, why is it wise to "follow it up" with the center? How is this done? What precaution should be observed?

26. State at least three precautions that should be observed when using a reamer.

27. Why does a reamer tend to follow the hole already made?

28. If the work is clamped and the drilled hole is not exactly in line with the machine spindle, what will be the result when the hole is reamed?

44. The counterbore is used to face around a hole, in order that a nut or a bolt may set square with the hole; or to enlarge

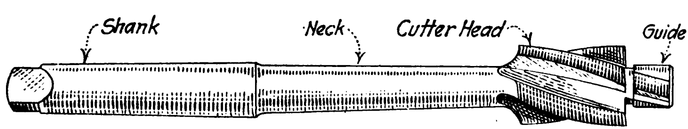


FIG. 47.—Solid counterbore with taper shank.

a hole to a given depth, as for the fillister head of machine screws and cap screws (see Fig. 12).

The standard solid counterbore (Fig. 47) consists of *the guide* (sometimes called the teat or the pilot) which is the size of the original hole; the *cutter head,* which is the size of the enlarged hole, and on the end of which the cutting "teeth" are formed; *the necked portion* which in the counterbore is fairly long to permit of enlarging a hole to a considerable depth if desired; and *the shank* which may be straight or taper. Grooves are cut either straight or spiral in the head

to form the upper faces of the cutting teeth. These grooves usually extend the whole length of the head to provide for the removal of chips, and to provide also a way for lubricating the cut. The teeth are backed off about 10° or 12° to give clear-

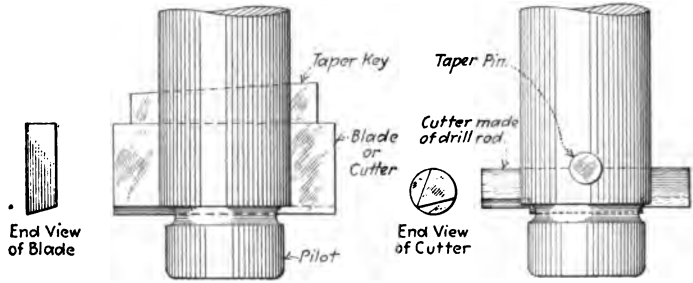


Fig. 48.—Two types of home-made counterbores with removable blades or cutters.

ance to the cutting edges. The cutter head is slightly tapered, smaller toward the shank, so that it will not bind.

Counterbores are made solid in the smaller sizes (Fig. 47) and usually with removable cutters or blades in the larger sizes

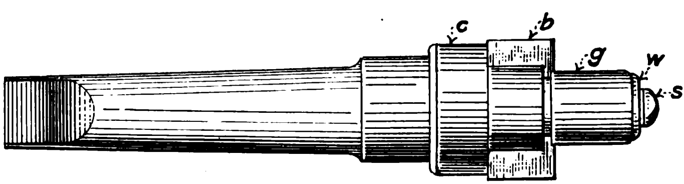


Fig. 49.—Combination Counterbore. (*Cleveland Twist Drill Co.*)

The large part *c* of the cutter head is a hardened steel collar forced into place after the slot for the blade *b* is cut. It projects somewhat over the slot and is ground true on the face. The blade is centered by a turned projection which fits the collar and is held square against the ground face of the collar by the guide bushing *g*, the washer *w* and the screw *s*. The bushing is slotted to fit over the blade and is hardened and ground. Various sizes of blades and bushings are quickly interchangeable.

(Figs. 48 and 49). In any case the cutting edges are at right angles to the axis of the counterbore in order to cut a *flat* surface.

A counterbore should have at least two cutting edges. They should be carefully and evenly ground in order to balance the cut. Sometimes one tooth of a counterbore with a wide cut is ground to cut only in the middle and a little deeper than the other tooth. This is to break the chip, and narrow the width of cut. It should, however, be so ground as to allow each tooth to do its share.

The counterbore is not designed for extremely accurate work therefore the body is usually made a trifle (.003"–.005") over the nominal size, and the guide is made one or two thousands under the size of the hole to be enlarged so that it will not bind. Oil the guide before using so that it will not rough up.

A cold chisel is much cheaper to make and much easier to sharpen than a counterbore and it is often desirable to chip off the scale around the hole before spot-facing or counterboring cast iron.

To avoid any danger of overheating and drawing the temper of a counterbore, run it at a somewhat slower speed than for drilling a hole of corresponding size, and apply the cutting lubricant freely.

45. The countersink may be differentiated from the counterbore in that it is used to enlarge the end of a hole to a cone shape, as for a flat head machine screw or a wood screw. The terms center-reaming and countersinking are both applied to the operation of making the center holes in work to be machined "on centers." The combination drill and countersink is the best tool to use for this operation. An important fact should be kept in mind—the included angle of a center hole is 60° and the included angle of the countersunk hole for the head of a wood

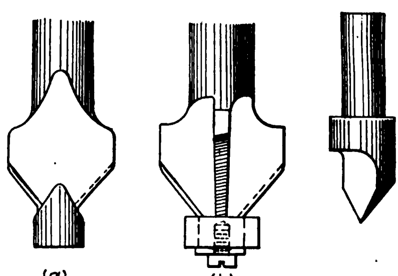


FIG. 50.—Types of countersinks for flat head screws.

screw or a standard flat machine screw is 82°;[1] do not get the 82° countersink and the 60° center-reamer mixed.

Three different kinds of countersinks for screw heads are illustrated in Fig. 50 (*a*) two-lip with guide; (*b*) four-lip with guide bushing and provided with screw and washer for holding various sizes of bushings to fit holes of different diameters; (*c*) the cheapest and best form of countersink for small screws.

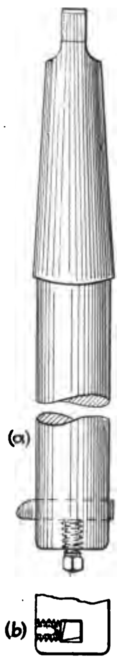


Fig. 51.—Boring tool for drill press.

Countersinks are run at fairly slow speed to avoid chattering. Hand feed is commonly used, and plenty of cutting lubricant should be applied.

46. Boring in a Drill Press.—It is sometimes practicable to bore a hole in a drilling machine, for example, when a drill or reamer of a suitable size may not be available. Further, when a perfectly straight hole is desired and a high degree of accuracy as to location is necessary, it is frequently drilled 1/16″ or more undersize, then *bored*, and finally reamed. If it is understood that a reamer will tend to follow the hole already made but that a boring tool tends to go straight (cutting more from one side of the hole than from the other side if necessary) the value of boring a hole to insure accuracy of shape and of location will be apparent.

Drill-press boring tools are made in many varieties and sizes. Fig. 51 illustrates a common type: The cutting tool is held in position by a set screw in the end of the bar as at *a*, or by a hollow set screw in the side of the bar as at *b*. When the boring tool is for any reason long and slender and inclined to spring it is necessary to take light cuts.

Questions on Boring, Counterboring, Etc.

1. What is the difference between "boring" and "counterboring" a hole?

[1] Angles of flat head cap screws are mostly 76° or 82° depending on the manufacturer.

2. What is the difference between "counterboring" and "countersinking?"

3. What is the difference between a machine screw countersink and a countersink (center reamer) for a lathe center?

4. State two cases when a boring tool may be used to advantage in a drilling machine.

5. Why should one select a boring bar as short and heavy as convenient to use?

6. Some shops provide three different sizes of counterbores for each of the most used sizes of fillister head screws, namely: the body size to head size counterbore; the tap drill size to head size counterbore; and the tap drill size to body size counterbore. What is meant by these terms? What is the purpose of each of these counterbores?

7. Why do you put oil on the teat of a counterbore? Is this true when counterboring cast iron?

TAPS AND TAPPING

47. Taps.—A tap is a master tool for cutting internal threads. Several forms of taps are used in machine work brief descriptions of which follow:

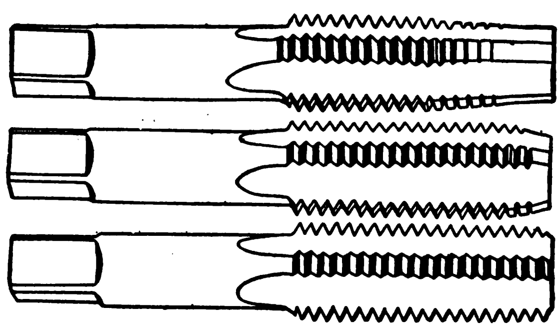


FIG. 52.—Set of hand taps taper, plug and bottoming.

Hand Taps.—Most internal threads are cut with taps, usually in a tapping machine or with a tapping attachment in the drill press. Many threads, however, must be tapped by hand. Figure 52 shows a set of machinist's hand taps squared on the shank end to receive the wrench (Fig. 53). Hand taps, except the sizes under ¼″ are made in sets of three taps, called taper, plug and bottoming. The first tap or taper tap

is tapered or "chamfered" back from the end at least six threads, the plug tap is chamfered about three or four threads, while the bottoming tap is merely backed off on the end teeth. Taps furnished in sets are of the same diameter unless otherwise specified, so that to tap a "through hole" it is only necessary to use the taper tap. Where the hole does not go through the piece ("blind hole") it is customary to start with the taper, follow with the plug, and, occasionally, if the hole is fairly shallow, finish with the bottoming.

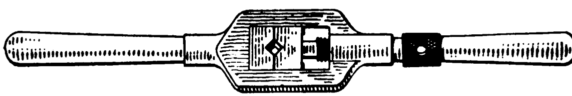


FIG. 53.—Tap wrench, used for turning taps or reamers.

Machine-screw Taps.—Hand taps under ¼" diameter such as 8–32, 10–24, etc. are catalogued as machine-screw taps and are used mostly in the form of plug taps. If necessary they may be quickly ground to either taper or bottoming form.

Serial Taps.—A set of serial taps consists of three taps of varying diameters (both outside and thread pitch diameters). These taps are distinguished from ordinary hand taps by shallow grooves (rings) cut around the shanks near the squared end, one, two and three rings respectively for the No. 1, No. 2 and No. 3 taps. No. 1 tap is the smallest and "roughs out" the thread, No. 2 takes a second roughing out, and No. 3 finishes the thread. They are useful for cutting threads in tough metal or when an especially smooth and accurate thread is desired.

A tapered tap has a uniformly tapering body or portion thereof and is used for tapping a full thread in a tapered hole. The most common example is the ordinary *pipe tap.* A tapered tap is best named for its particular purpose, thus avoiding confusion with the first tap or "taper tap" in a set of hand taps.

Tapper tap, (Fig. 54), is the name given to the tap whose chief use is in a special nut tapping machine. The shank is

longer than a hand tap of the same diameter and invariably is smaller than the root diameter of the thread. This is for the purpose of holding a number of nuts after tapping. When no more nuts can be held on the shank the tap is removed and the tapped nuts slid off the shank. Usually the tapper tap is given a longer taper (chamfer) than the taper tap of a hand set, to lighten the work of each tooth. If considerable

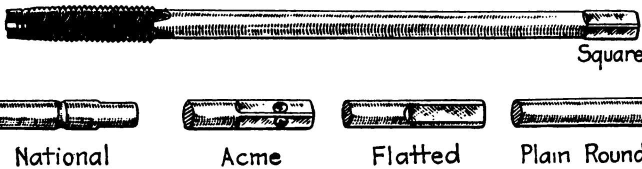


FIG. 54.—Tapper tap and forms of shank ends.

taper is given, care must be taken not to ream the hole instead of tap it.

Some manufacturers turn the first six or eight threads taper, not merely turn the outside taper, but cut the threads on a taper. This eliminates to a certain extent the tendency otherwise to ream the hole and also improves the cutting qualities of the tap and produces a "cleaner cut" thread. Also several of the straight threads are chamfered to reduce the amount of

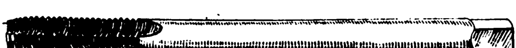


FIG. 55.—Pulley tap.

work for the successive cutting edges. Tapper taps are provided with various forms of shank ends to fit the holders of nut tapping machines in common use.

Pulley taps, Fig. 55, are special hand taps for tapping the set screw and oil cup holes in the hubs of pulleys. The shank is long enough to reach through a hole drilled in the pulley rim which is made substantially the size of the shank and thus affords a means of aligning and steadying the tap. The "extension drill" for the hole in the hub may be made

by soldering a straight shank drill in a hole drilled in the end of a suitable piece of cold rolled steel.

Machine taps are made for general use in special tap holders in drilling machines. One of the best known and most efficient holders is the Beaman and Smith holder (see Fig. 58). A plug hand tap may be used as a machine tap in a drilling machine provided with spindle reverse gears, or in certain tapping attachments if a suitable holder for the squared shank end is provided. Do not use a chuck to hold a tap over 3/8″ diameter because it is likely to injure the chuck.

The gun tap, (Fig. 56), is very efficient when used either as a hand tap or in a machine for power tapping. Because of the shape of the initial cutting edges which have both rake and

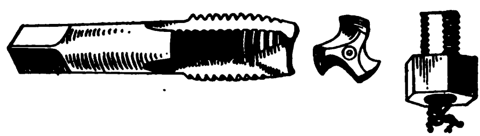


Fig. 56.—Gun tap. (*G. T. D.*)

shear, it is unnecessary to chamfer more than three or four threads, thus avoiding the tendency to ream. Further it does not clog because the chip "shoots" out ahead of the tap.

48. Advantages of Tapping by Power.—Tapping by power reduces the expense and inaccuracy of tapping by hand. In addition to being much easier and quicker, it is steady and even, and affects a saving in the breakage of taps, and also prolongs the life of the cutting edges. Because of the firm manner of holding and turning the tap, the thread produced is clean and true.

49. Tapping Attachments.—The spindle reversing feature, Fig. 11, in itself is very efficient for power tapping when used with judgment and skill. However, no automatic stop being provided, the operator must reverse or stop the spindle at the proper time. It will of course be understood that the feed stop (30, Fig. 9) only stops the advance of the spindle and does not stop its rotation.

An auxiliary attachment, such as described in the following paragraph, when used in connection with the spindle stop practically eliminates the chances of error or accident.

50. Auxiliary Tapping Attachments.—There are, in the market, several kinds of tapping attachments provided with taper shanks to fit the drill press spindle. Figure 57 shows a tapping attachment (Pratt and Whitney Co.) designed to be used with the reversing mechanism of the drill and using also the spindle feed stop (30, Fig. 9). The tap holder *A* is held up within the body *B* of the attachment by spring tension. A slight pressure serves to start the tap, and the advancing tap pulls the spindle with it until the stop is reached. After the spindle has stopped advancing the tap still threads its way into the hole against the force of the spring until the driving pins *L* are disengaged and the tap ceases to revolve. Reversing the spindle serves to withdraw the tap. If the spindle stop is properly set, duplicate holes may be tapped the required depth without difficulty.

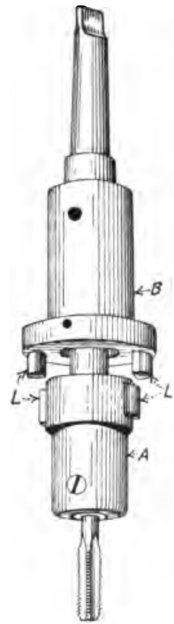


Fig. 57.—Leland tapping attachment. *(Pratt & Whitney Co.)*

Figure 58 illustrates the Beaman and Smith safety drill and tap holder for use in a machine having a reversing mechanism.

Figure 59 shows the Errington Auto Reverse tapping chuck which is a tapping attachment with the reversing mechanism contained. This chuck requires no reversing mechanism on the drill press, as it drives the tap in, stops automatically, and backs tap out with quick return by simply raising (not stopping or reversing) the drill spindle. It fits the socket of any drill press and can be used for right or left threads. Certain of the larger sizes have attachments for setting studs or nuts which are very efficient.

51. Tapping in a Drilling Machine.—Make the set-up carefully, having the holder or attachment tight in the spindle and

properly adjusted, the work so held that it cannot twist or cramp, and the tap sharp and running true or arranged to "float" in the holder. The spindle must be perfectly free to slide in the sleeve—no feed being necessary in the tapping operation except in certain cases a "follow-up" hand feed. The speed should be slow—half to two-thirds of the speed for

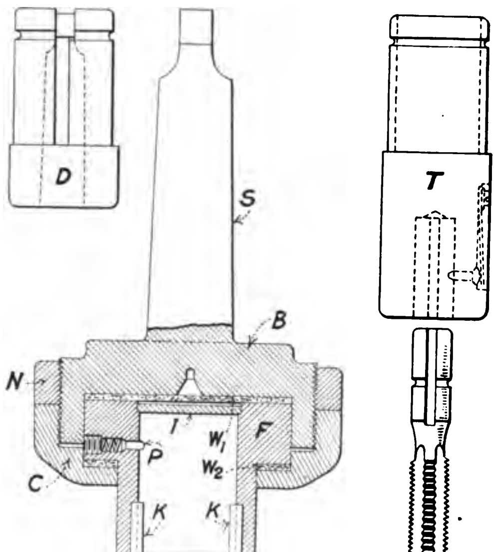


FIG. 58.—Beaman & Smith safety drill and tap holder.

S is the shank and B the body recessed to receive the friction socket F. The cap C screws on the body and holds the friction tap holder F as tight between the fibre disk W_1 and washer W_2 as is necessary to drive the drill or tap. N is a check nut for securing the cap C in place after the friction adjustment is made.

Special sockets, T and D as shown, are required to hold the tap and drill. Taps with special shanks may be obtained from almost any tap manufacturer. Drill sockets are furnished with Morse taper holes for any desired size of drill.

The sockets are inserted in the holder F and are kept from turning by the keys K and from falling out by the small spring plunger P. It will be observed that the tap is held in its socket in a similar way. The thrust of the socket T or D is against the disk I, which serves to protect the fibre disk W_1.

drilling. Have at hand plenty of cutting lubricant and apply it freely when tapping; provide a means of catching the surplus, however, in order to avoid wasting the lubricant and

messing the machine. (Lard oil is best for steel and soap or tallow works well for tapping cast iron.) Enter the tap in

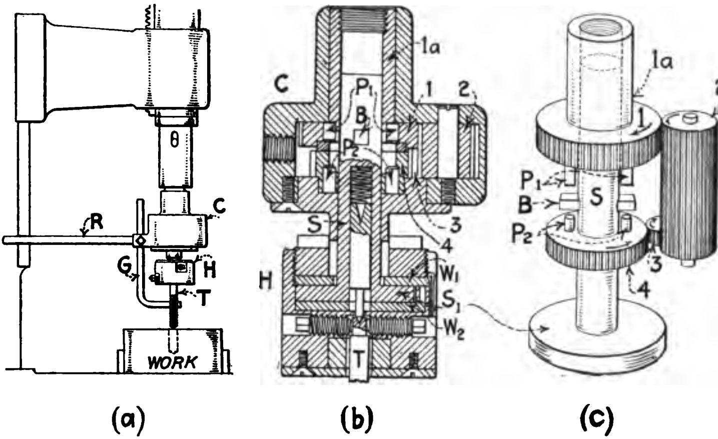


Fig. 59.—Errington automatic reverse.

(*a*) Mechanism arranged in drill press. (*b*) Vertical section through reversing mechanism and friction holder. (*c*) Sketch of auto reverse mechanism somewhat elongated for clearness.

C, casing of automatic reversing mechanism. *H*, Friction holder for tap or stud setter. *G*, Adjustable depth gage. *R*, Stop rod (prevents case *C* from turning). *T*, Tap (stud setter may be substituted). *S*, Spindle, provided with friction flange S_1. *B*, Clutch bar (end view in (*b*) side view in (*c*)). (1), Driving gear. (2) and (3) Intermediate gears. (4), Reversing gear. P_1, Driving gear clutch pins. P_2, Reversing gear clutch pins. W_1 and W_2, Friction washers.

The auto-reverse permits of rotating the spindle *S* in opposite directions with a constant forward motion of the drilling machine spindle. A suitable shank is fitted to screw into the hub (1*a*) of the driving gear (1), and consequently this gear rotates with the drill press spindle. As the drill press spindle is fed down, the clutch pins P_1 engage the clutch bar *B*, both ends of which project radially from the spindle *S* as shown in (*c*), and the spindle *S* rotates clockwise to drive the tap into the hole. The gage *G* serves to stop the down feed of the gear (1) but the tap keeps on turning until the spindle *S* is pulled down, by the threading in of the tap, far enough to disengage the clutch pins P_1 at which time the spindle *S* stops turning. As the operator raises the drill press feed handle, the reversing gear (4) is raised to engage the clutch pins P_2 with the clutch bar *B*. This starts the spindle *S* and the tap in the counter-clockwise direction and as the operator lifts the feed handle the tap is backed out of the hole.

The reversing gear (4) gets its motion from the driving gear (1) through the intermediate gears (2) and (3) as shown in (*c*).

the hole with just enough pressure to make it bite after which it will feed itself. When the hole is tapped the depth required,

reverse the direction of rotation of the tap and with a slight upward pressure on the feeding lever back the tap out. It may be necessary in a fairly long hole to reverse part of a turn once or twice during the tapping operation to break the chip.

NOTE.—For tap drill sizes see p. 39 and also List of Tables. p. 397

Questions on Taps and Tapping

1. Name the three taps in a tap set. What is the purpose of each one?

2. When threads are tapped in tough metal, what should be done to keep them from tearing?

3. What lubricant is best when tapping cast iron? Steel? Brass? Aluminum? Copper?

4. How far should a screw enter a tapped hole in order to give sufficient strength?

5. What is a "blind" hole?

6. If the effort to turn the tap is continued after it bottoms, wha will be the result?

7. How do you use a scale when counting the number of threads per inch? What is a "pitch gage?"

8. How may the pitch of the thread in a nut be determined with a whittled stick, if there is no tap or bolt to fit it?

9. What size is the largest drill that will pass through the nut?

10. What is a tap drill? What is meant by a "body size" drill?

11. Why is a tap drill smaller than the outside diameter of the bolt?

12. What form of thread have S. A. E. Standard screws?

13. How many threads per inch has the 3/4" U. S. Standard screw? The 3/4" S. A. E. Standard screw? (See List of Tables p. 397.)

14. Why are the screws used in automobile work of finer pitch than those used in machine tool manufacture?

15. In common practice, is the tap drill size equal to the root diameter of the thread? Is it larger or smaller?

16. State three objections to the use of a tap drill that will give a full thread.

17. Calculate the size of the tap drill for 5/8–11 U. S. Standard screw. Calculate the size of the tap drill for 5/8–18 S. A. E. Standard screw.

18. Calculate the size of the tap drill for 7/8–9 U. S. Standard screw. Calculate the size of the tap drill for 7/8–14 S. A. E. Standard screw.

19. Calculate the size of the tap drill for 5/16–18 U. S. Standard screw. Calculate the size of the tap drill for 5/16–24 S. A. E. Standard screw.

20. When two pieces are to be held tightly together why not tap both pieces?

21. If it is desired to tap a slightly larger hole in a nut so it will be a free fit on a thread, how can this be done with a standard size tap? Ans. Wrap waste around the tap.

22. Before attempting to re-tap an old nut, what precaution should be taken? Why? Ans. Be sure it is not case-hardened.

23. It occasionally happens that a ½″ screw will not fit a tapped hole which appears all right. What caution must be observed when using ½″ set screws, ½″ taps and ½″ dies? Ans. Beware of ½–12 threads.

24. How is a tap sharpened? How is it "backed off?"

25. Explain the principle of the operation of the bevel gears and the clutch in the reversing mechanism or tapping attachment (see Fig. 11).

26. State four advantages of tapping by power.

27. Explain by sketch and description the action of an auxiliary tapping attachment by means of which duplicate holes may be tapped the same depth using the spindle stop.

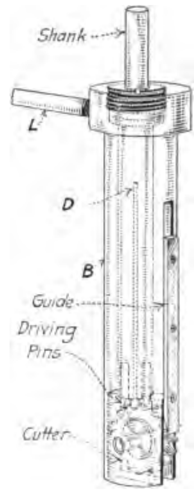


FIG. 60.—Key seat milling device, (*National Machine Tool Co.*) showing method of driving the cutter. The body *B* is cylindrical and fits the hole to be keyseated (or the bushing). The cutter has staggered teeth, sharpened by grinding on the face. The spindle *D* is off-set from the center of the body. It is provided on the lower end with cutter driving pins and at the top with either a straight or taper shank. The handle *L* may be arranged against any suitable stop to keep the body from turning. The guide serves to keep the keyseat in alignment.

CUTTING A KEYSEAT IN A DRILLING MACHINE

52. The Keyseating Miller.—In the manufacture of large numbers of duplicate pieces that require keyseats a keyseating machine is invaluable. In many shops, however, such a machine is not available and for cutting the keyseats in gears, pulleys, clutch members, etc. the machinist has used the shaper (see page 111) or in the larger pieces has possibly had to resort to chipping and filing.

A keyseating attachment for use in the drilling machine is illustrated in Fig. 60. This attachment offers a very practicable and efficient method of milling internal keyways and is decidedly quicker and better

than the shaper and often more advantageous even than a keyseating machine since it will mill a keyseat on the drill press without further set-up.

The keyway miller is made in twenty sizes to cut keyways from 1/8" to 1" wide. Eccentric bushings may be used if it is desired to keyseat different sizes of holes with the same miller.

FIG. 61.—Milling keyseats in an upright drilling machine.

Special bushings with wedge shape flanged bases and holes perpendicular to base surfaces are used for milling taper keyseats.

A typical set-up is illustrated in Fig. 61. The body of the miller shown is 1" in diameter and is used in connection with an eccentric bushing 1 3/8" in diameter to fill the hole in the work. The size of the keyseat being cut is 1/4" wide and 1/8" deep and may be milled at the rate of 2" to 4" per minute.

THE SHAPER

CHAPTER IV

SHAPER CONSTRUCTION

53. Introduction.—The function of the shaper is, primarily, the production of flat surfaces. The work is held on an adjustable work table or more often in a vise fastened to the work table, while the cutting tool, which is given a reciprocating motion, that is, caused to move forward and back, peels off a chip on the cutting stroke. During the return stroke the feed operates to move the table (and work) the desired amount.

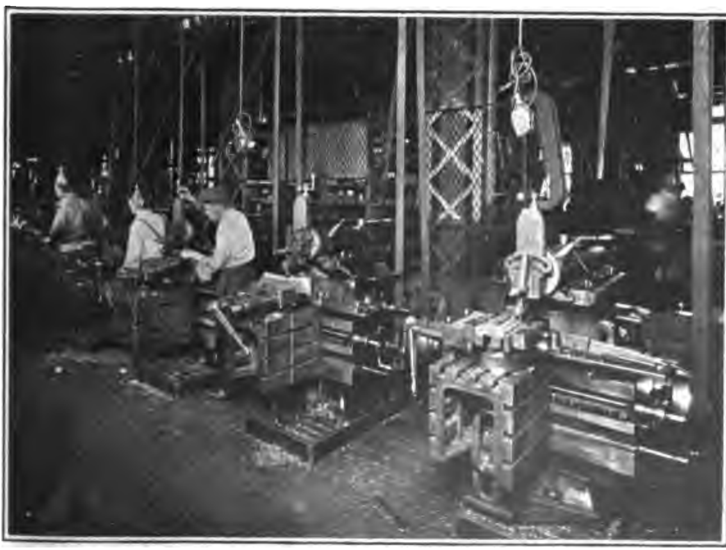


Fig. 62.—Gould and Eberhardt shapers in a tool department. (*Photo Brown Bros.*)

Shapers are classified as to size (14," 16," 20," etc.) by the maximum length of the cut that may be taken, and a standard shaper of a given size will hold and plane a cube of that size. Shapers are made in a variety of types, some of them being very special in their application. The different manufacturers of course differ to a considerable extent in detail of design and construction for a given type.

The crank shaper (Fig. 63) in which the tool carrier is driven forward and back by a vibrating arm operated by a crankpin in the main driving gear or "bull wheel," and in which the feed is transmitted to the work table, is generally recognized as the ~~most efficient~~ design and is so commonly used as to be termed standard.

54. The Value of the Shaper.—The relative values of different methods of doing a job, or of the kinds of machines to use, is one of the most profitable and interesting studies in machine shop work. For example, for a small number of pieces it may be better to plane one piece at a time in a shaper, for a larger number of pieces it may be more efficient to set up and plane several at a time in a planer. It may be cheaper and quicker to take one or more cuts on say twenty-five pieces in a shaper or planer rather than in a milling machine; on the other hand if there were enough pieces to make the extra initial expense worth while, it probably would be much better to provide a special fixture and a special cutter, and machine them in the milling machine.

The shaper is especially adapted to small work which may be held in a vise bolted to the work table. The tool head is so constructed as to permit of horizontal, vertical, or angular cuts being taken. For tool room work such as punch and die work, jig and fixture parts and on short work for other special tools or machines, the shaper is practically indispensable.

The shaper cutting tool is easily ground the desired shape for the cut to be taken and when dull may be quickly sharpened. The range of stroke and position of stroke; of vertical adjustment of work table; of feeds—lateral, vertical and angular,

together with the adaptability of the single cutting tool, serve to make the shaper more efficient for many jobs than the milling machine. This is especially true in model work or tool work involving at most only a few pieces. On the average shorter cuts within its capacity the shaper is more efficient than the planer for the following reasons: It costs less to buy, it takes less power to run, occupies less space in the shop, is about one-third quicker, the work is more easily adjusted, and generally speaking less skill is required in operation.

A wide variety of very accurate work may be easily and quickly accomplished in the shaper if the machine is in good condition, clean and well oiled, and the operator understands its construction and the principles of its operation.

55. Parts of Shaper.—On the following pages is illustrated and described an excellent example, as regards both detail of design and efficiency, of a standard shaper. In connection with your job in the shaper, study the illustration (and machine) and text carefully and learn the names and functions of the parts.

A machinist who can intelligently run a lathe made by a manufacturer in Cincinnati will have no particular difficulty in operating a lathe made by another company in Hartford. These lathes may have different features in design but, in principle, they are alike in construction and operation. So with shaper work, a shaper is built for certain operations and the machinist who understands the construction of a given standard shaper will have no trouble in understanding quickly the constructional features—that is, the functions of the various levers, handles, etc. of any shaper.

PRINCIPLES OF THE CRANK SHAPER DRIVING MECHANISM

56. The Cutting Stroke and the Return Stroke.—The ram is actuated by a slotted vibrating arm *M*, (Fig. 64) which is pivoted at its lower end to the column while the upper end is connected by a link *A* to the adjustable clamp block *B* which is clamped to the ram. The vibrating arm is caused to

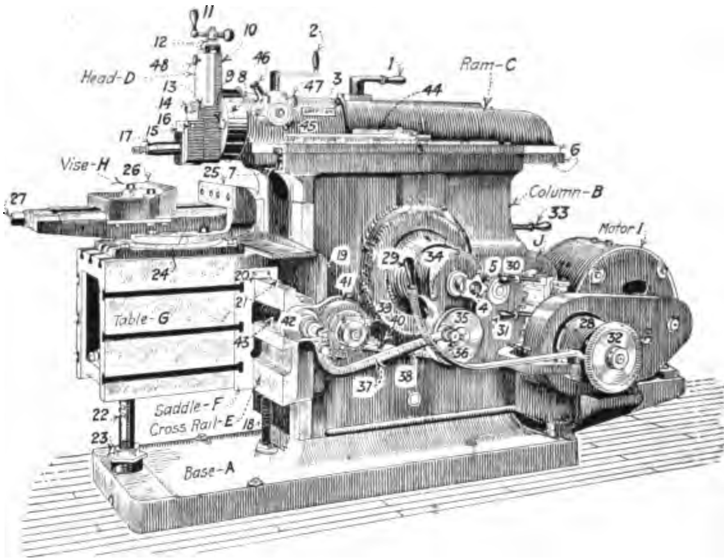


FIG. 63.—Shaper. (*American Tool Works Co.*)

PARTS OF THE SHAPER

Index to Unit Names

A. *Base*, pan shaped to keep oil off floor.

B. *Column*, main support for operating mechanism. The top is machined and scraped to form a flat bearing for the ram.

C. *Ram*, carries the tool head. Cast in cylindrical form to give strength and stability, has, in operation, a reciprocating motion on the column which is actuated by a crank driven mechanism within the column. The length of the stroke and the position of the ram with reference to the work are adjustable.

D. *Head*, holds the tool and contains the down feed; is swivel in construction to permit the tool to be fed at any desired angle with the top surface of the table.

E. *Cross rail*, held in any desired position on a vertical slide machined and scraped in front of the column. Carries the saddle and work table, also part of the table feeding mechanism.

F. *Saddle*, table connection to cross rail, and work support when table is removed.

G. *Work table*, bolted to saddle; is provided with T-slots. When constructed to swivel on the saddle, and also to be tilted, it is called a universal table (see Fig. 81). Most shaper work is done in a vise bolted to the table.

H. *Vise*, work holder on swivel base.

I. *Motor*, initial driver; constant speed; direct geared to speed box shaft.

J. *Speed box* and *speed-control mechanism* (see also Fig. 66).

K. *Table feed mechanism*, automatic transverse feed to table *G* (see following part numbers 34 to 43 inc.).

L. *Power down-feed mechanism*, automatic feed to tool head *D* (see following part numbers 44 to 48 inc.).

M. *Vibrating arm* (not shown, see Fig. 64).

N. *Bull wheel*, main driving wheel (not shown, see Fig. 64).

Index to Part Names

1. *Binder lever* for securing ram to vibrating arm *M*.
2. *Crank* for operating ram positioning screw (first loosen binder lever 1).
3. *Pointer* for indicating the length of tool travel.
4. *Stroke setting shaft* (regulates position of crankpin in bull wheel *N*).
5. *Knob* for locking stroke setting shaft.

6. *Ram bearing surfaces.*
7. *Oilers* and *wipers* for sliding surfaces (contain felt inserts to wipe off dirt and retain oil):
8. *Swivel plate* for head, has graduations, in degrees, for angular positions of tool travel.
9. *Clamping bolts* for locking head to ram.
10. *Tool head slide.*
11. *Hand feed crank* on screw, for vertical feed to tool.
12. *Graduated micrometer collar* on screw, for fine adjustment.
13. *Clapper-box* with angular adjustment.
14. *Clamping bolt* for clapper-box.
15. *Tool block* or *clapper*, holds tool post.
16. *Hinge pin* for tool block.
17. *Tool post*, secures tool in position.
18. *Screw for raising or lowering cross rail*, moved by miter gears. The rod and handle are on other side of the shaper.
19. *Clamping screws.* Used to secure rail to column after adjustment up or down. It is imperative that these screws be loosened slightly before raising or lowering the table and tightened when the table is in position.
20. *Oiler and wiper*, similar to No. 7.
21. *Full-length taper gib*, for taking up wear and regulating fit between cross rail and saddle. A gib similar to this is located between the ram and the column.
22. *Table support.* This bears on base and is secured to table. It is adjustable to suit table height. Used when heavy work is placed on the table.
23. *Lock nut* on foot of table support, used for fine adjustment.
24. *Swivel base for vise*, graduated at joint for angular positions of vise body.
25. *Stationary jaw* and *vise body* combined.
26. *Movable jaw of vise*, moved by screw No. 27.
27. *Screw for clamping work* in vise jaws.
28. *Friction*, connects motor gears (or single drive pulley) to speed box shaft. A brake is furnished at other end of driving shaft for stopping ram quickly after friction is released.
29. *Friction* and *brake engaging lever*, pushed to the right to operate friction clutch (28), to the left to operate brake.
30. *Speed-changing lever*, operates upper pair of slip gears.
31. *Speed-changing lever*, operates lower pair of slip gears.
32. *Hand wheel* on driving shaft, used to revolve gears so they may be engaged when motor is not running, also to move ram slightly when setting tool, etc.
33. *Back gear shifting lever*, operates either set of the double train of back gears between speed box and bull wheel. For detail see Fig. 66.
34. *Feed gear bonnet*, carries feed operating gears, upper gear revolves with bull wheel and engages with lower gear which is located back of reverse plate (35).
35. *Feed reverse plate*, carries reverse knob (36).
36. *Feed reversing knob* for changing position of feed crankpin so that table feed may be arranged to take place on the reverse stroke. Crankpin engages either one of two holes in opposite sides of center of the feed gear.
37. *Feed operating link*, connects feed gears in bonnet with feed device on cross rail.
38. *Distance link*, controls the distance between bull wheel center and feed device on cross rail to relieve feed operating link (37) from strains when rail is adjusted up or down on column, and maintain correct center distances at all times.
39. *Knob* for regulating the amount of feed per stroke. Operates a worm and wormwheel mechanism which exposes any number of notches in a feed disk which is engaged by pawl (40).
40. *Pawl knob*, stops and starts table feed in either direction. When pawl is in neutral position, it does not engage feed disk notches and there is no feed.
41. *Large feed gear*, revolves on stationary stud in cross rail.

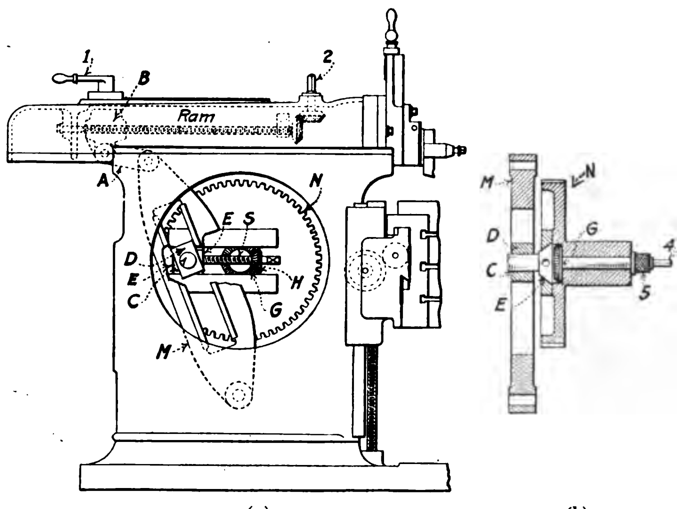
NOTE.—Gears 41 and 42 are under gear guard.

42. *Feed pinion* on table feed screw (43).
43. *Table feed screw*, for moving saddle and table on cross rail. Feed screw nut is attached to rear wall of saddle *F*. For hand feed put crank handle on squared end of screw.
44. *Dog* (adjustable), operates down feed lever (45) at each return stroke of the ram.
45. *Down feed lever* actuates pawl (46).
46. *Pawl knob on down feed.* The pawl engages feed notch wheel inside of casing, which transmits motion to down feed screw through two shafts in ram and two sets of miter gears one gear forming a nut on the down feed screw.
47. *Feed regulating knob*, similar to (39 on cross rail.
48. *Thumb screw*, secures down feed screw against turning when power down feed is in operation.

move back and forth by a crankpin *C* which is carried by the driving gear or "bull wheel" *N*. The crankpin operates in a block *D*, provided with wide bearing surfaces, which slides in a slot in the vibrating arm. As the bull wheel revolves the crankpin travels in a circular path, and through a part of its

travel moves the arm in one direction and during the remainder of its travel moves the arm in the opposite direction. The position of the crankpin with reference to the center of the bull wheel determines the distance the upper part of the arm moves back and forth, and this determines the movement of the ram, that is, the length of the stroke.

57. Adjustment for Length of Stroke (Fig. 64).—The crankpin *C* carrying the block *D* is *fastened* in a *second* block *E* into which the screw *S* is threaded. Thus the crankpin may be



(*a*) (*b*)

FIG. 64.—Shows driving mechanism from bull wheel *N* to ram. also mechanisms for adjusting *length* of stroke and *position* of stroke. In vertical section (*b*), gear *H* is not shown and in (*a*) a portion of the vibrating arm has been cut away.

moved along a radial slide in the bull wheel by turning the shaft (4) which operates the screw *S* by means of the bevel gears *G* and *H*. Consequently, as the shaft (4) is turned (by means of the handle supplied) the crankpin is moved towards or away from the center of the bull wheel, depending on which direction the shaft is turned. A convenient index plate and pointer (3) (Fig. 63) are provided for reading the length of stroke. The shaft (4) is locked by turning the

knob (5) to the right after the correct length of stroke is obtained. (For (4) and (5) see also Fig. 63.)

58. Adjustment for Position of Stroke (Fig. 64).—After the correct length of stroke is obtained, the adjustment for the position of the ram, so that the extreme end of the cutting path of the tool may be correctly placed with reference to the work, is quickly accomplished. Loosen the clamp block *B* by turning handle (1) next bring the vibrating arm *M* to its extreme forward position by turning the driving pulley, or handwheel, by hand, then by turning handle (2) adjust the

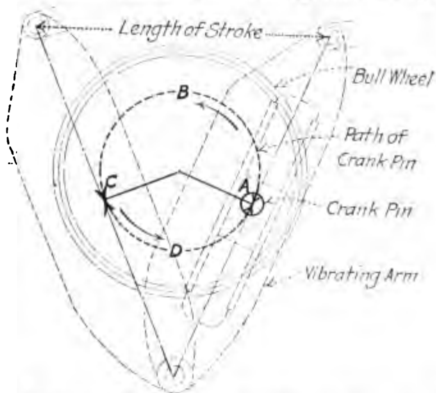


Fig. 65.—Shows principle of quick return (Viewed from right-hand side.)

cutting tool about one-fourth inch or one-half inch beyond the edge of the work. The adjustment for the length of the stroke should be made before the adjustment for position.

59. The Quick Return.—Due to angular position of the vibrating arm at the point of reversal, the ram travels faster on the return stroke than on the cutting stroke. The principle of this "quick return" is shown in Fig. 65. In the circular path of the crankpin the arc *CDA* represents the *time* of the return stroke and the arc *ABC* the *time* of the forward or cutting stroke, and the ratio (average) is about 2 :3 in most shapers. That is, it takes about one and one-half times as long to make the cutting stroke as it does to make the return stroke (ratio $2:3 = 1:1\frac{1}{2}$).

60. Speeds of Shaper.—At a given speed of the driving gear a shaper will make a constant number of strokes per minute whether they are long or short. To obtain a given *cutting speed* per minute for the tool, the shaper must have twice as many strokes for a cut 2″ long as for a cut 4″ long. Therefore, to allow for the different lengths of stroke (and also for the different metals to be cut) the shaper is provided with different speeds.

In the shaper with cone pulley drive the speed changes may be obtained by changing the belt on the various steps of the pulley. In the shaper with single pulley drive or individual motor drive the different speeds are obtained through *speed change gears.* The gearing, etc., which constitute the speed change mechanism is in effect the same as the mechanism of a "geared head" of a lathe or milling machine but in the shaper is termed the "speed box."

The smaller shapers (14″ and under) are usually provided with four speeds; in the larger sizes the number of speeds is doubled by the use of back gears.

The speed-box illustrated in Fig. 66 is the unit removed from the shaper shown in Fig. 63, and Fig. 67 shows the development of this shaper drive. There are two series of four speeds each, one series through the back gear train *H–I* the other through the back gear train *J–K* as follows:

Speeds	Lower Lever (31) moves gears *A* and *B*	Upper Lever (30) moves gears *G* and *F*	Gear runs	Strokes per minute
First speed (slowest)	Left	Left	*B-E-D-G-H-I*	8
Second speed	Right	Left	*A-C-D-G-H-I*	11
Third speed	Left	Right	*B-E-C-F-H-I*	15
Fourth speed	Right	Right	*A-C-F-H-I*	23
Fifth speed	Left	Left	*B-E-D-G-J-K*	34
Sizth speed	Right	Left	*A-C-D-G-J-K*	49
Seventh speed	Left	Right	*B-E-C-F-J-K*	71
Eighth speed (fastest)	Right	Right	*A-C-F-J-K*	105

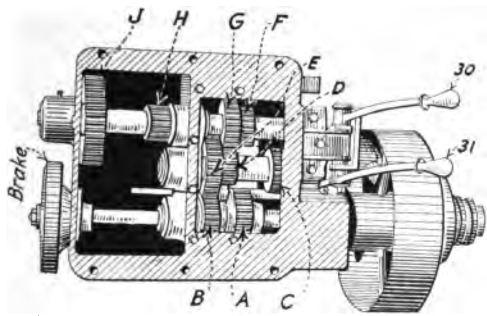


Fig. 66.—Speed box removed from shaper illustrated in Fig. 63.

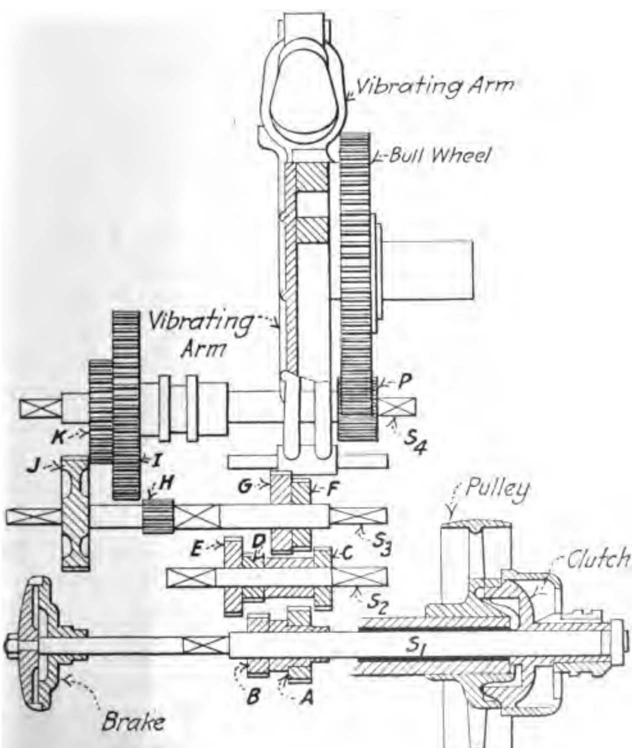


Fig. 67.—Shaper driving mechanism.

It will be observed that the speed at which the final driven gear (bull wheel) revolves is determined by the relative sizes of the driving and follower gears in the various pairs of gears which make up the compound gear trains which serve to transmit motion from the shaft S_1 to the bull wheel. Thus in the slowest speed B is smaller than E, D is smaller than G and H is smaller than I which makes for a reduction of speed in each pair of gears. To produce the next slowest speed the lower lever is moved out. This disengages B with E and engages A with C which serves to slightly increase the speed of S_2 and this increase is of course carried on to S_3 and the bull wheel.

61. The work table may be *fed* horizontally either by hand or by power; and may be *adjusted* vertically to provide for different jobs, which may vary considerably in height. The table is bolted to a saddle, and the saddle is gibbed to the cross rail which provides a suitable bearing surface for the horizontal (feeding) movement of the work table when the feed screw is turned. Either a rapid traverse of the table or the desired amount of "hand feed" may be obtained by means of a crank placed on the squared end of the feed screw. The automatic feed will presently be explained. The front face of the column of the shaper is finished to form a suitable bearing surface for the vertical adjustment of the cross rail. That is, the cross rail together with the saddle and table may be raised or lowered. This is accomplished by means of a vertical screw operated through bevelled gears by a horizontal shaft, the squared end of which is on the side of the machine. The same crank handle that is used for hand feed is used here. Clamping bolts are provided on both sides of the shaper to securely bind the cross rail to the column. Whenever the vertical adjustment of the table is made these bolts should first be loosened, the adjustment made, and then the bolts tightened to give rigidity to the work. As a further method of imparting rigidity to the table and work under the pressure of the cut an adjustable brace is arranged from the base of the machine to the table. If the table is to be lowered it will of course be necessary to loosen this brace.

The work table is provided with T-slots on the top and on both sides for the purpose of holding bolts for clamping the work or the work holding devices. In nearly all shapers the table is permanently bolted to the saddle but at an additional cost certain manufacturers will furnish a "universal table." This table may be swiveled on the saddle plate thus providing an angular adjustment of the work at right angles to the direction of the stroke. Also, the top being hinged on the back side, the front may be raised thus providing an angular adjustment in the direction of the stroke. These table swivel and tilting features are very useful where any considerable amount of angular (bevel) or taper planing must be done. See Fig. 81.

Questions on Shaper Construction

1. In a crank shaper how does the bull wheel drive the vibrating arm?

2. What is a crank shaper?

3. What is the use of the slot in the vibrating arm?

4. Where and how is the crankpin held?

5. How is the screw turned to move the crankpin? Why are bevel gears used? Where is the check nut? How does it serve to hold the crankpin in position?

6. How much movement has the vibrating arm when the crankpin is on center? Why? Away off center?

7. What is meant by the stroke of a shaper? Cutting Stroke? Return stroke? What is the maximum length of stroke of the shaper on which you are working? What size shaper is it?

8. Is there a link between the hinge pin and the vibrating arm, or between the arm and the ram? What is the use of the link?

9. What is the reason for the slot in the top of the ram?

10. How is the vibrating arm connected to the ram? How is the position of this connection changed? How does it effect the "position of the stroke?" Why are bevel gears used between the handle and the screw?

11. Explain the "quick return" of the shaper ram.

12. What clamping bolts must be loosened before adjusting the table vertically? How much should they be loosened? Why?

13. How is the elevating screw oiled? How are the thrust bearings oiled? How often?

14. What amount of vertical adjustment of the table is possible?

15. What is the value of the table brace support?

16. Why does turning a screw move the work table horizontally? How is this screw turned by hand? What is this movement called?

17. How are the various speeds obtained in the shaper? What is the need of having several speeds? Are back gears provided in a shaper? Give reason.

18. On what kinds of work is the shaper particularly useful.

19. Give several reasons why the shaper is better than a planer for small work.

62. Feeding Mechanism.—The automatic feed of a shaper is obtained by causing the feed screw to make part of a revolution. The feed screw is actuated by a pawl[1] which engages

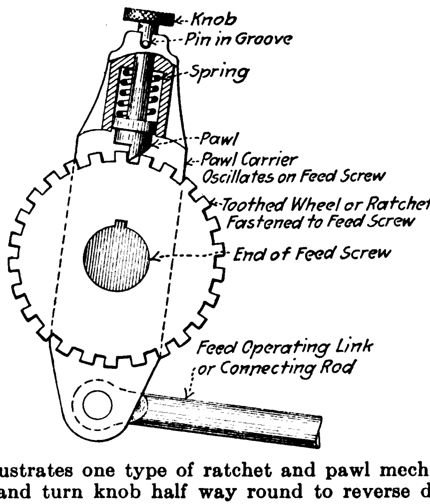


Fig. 68.—Illustrates one type of ratchet and pawl mechanism. Lift pin out of groove and turn knob half way round to reverse direction of feed, one-quarter turn for neutral.

a notched wheel, (Fig. 68), which is either fastened to the screw or transmits its motion to the screw through gears.

When the pawl is "in," it *operates* once, and *gets ready* to operate again, during each revolution of the bull wheel. This is because the oscillating motion of the pawl carrier

[1] *Pawl.*—A hinged or pivoted piece, or a piece arranged in a pivoted carrier (pawl carrier), having an edge made to engage with the teeth of a notched wheel for the purpose of giving motion to this wheel in a given direction.

moves the pawl *forward* and then *back* one or more teeth on the notched wheel. This oscillating motion of the pawl carrier is transmitted either (1) from a crankpin arranged to make one cycle when the bull wheel revolves once (see Fig. 69 also numbers 35, 36 and 37 Fig. 63) or (2) from an eccentric on the bull-wheel hub (Fig. 70), which of course completes one motion when the bull wheel revolves once.

If the feed motion is transmitted through a *feed rocker arm* as is the case when actuated by an eccentric on the bull wheel

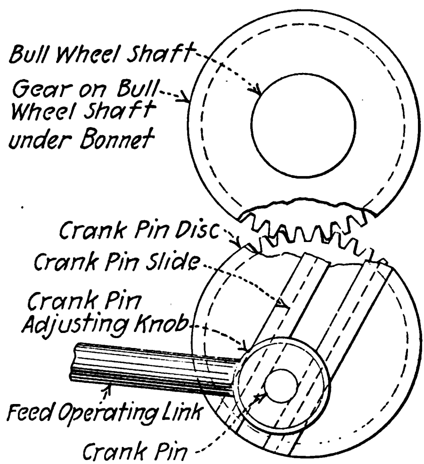


Fig. 69.—Shaper feed mechanism (operated by gears). The upper gear is fastened to the hub of the bull wheel and the lower gear is carried on a stud shaft in a bonnet. The crank pin disc is located in front of the lower gear. The gears are equal therefore each revolution of the bull wheel causes an oscillating movement of the feed operating link.

(Fig. 70), then the position of the feed adjusting knob, one side or the other of the rocker arm center, determines whether the feed shall be during the forward or return stroke.

This same principle applies in shapers that have the feed operating link or connecting rod actuated by a *crankpin* in a slotted disk, the disk being revolved by means of gearing at the outer end of the bull wheel hub (see Fig. 69 also description 36, Fig. 63).

The feed should take place *on the return stroke* because to feed during the cut puts undue strain on the feeding mechanism.

The amount of automatic feed is governed by the number of teeth the notched wheel moves at each return stroke of the shaper, and this is controlled by the position of the feed-link adjusting knob in the rocker-arm slide (Fig. 70), or in the crankpin slide (Fig. 69). On center there is no feed and the greater the distance from center the more the feed.

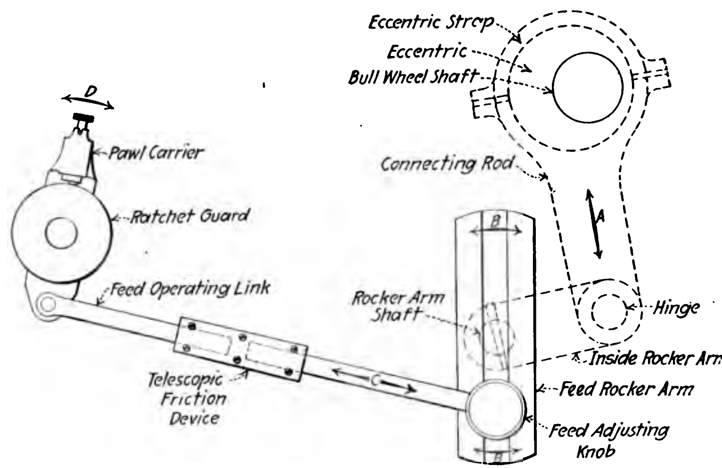


FIG. 70.—Shaper feed mechanism (operated by eccentric). The eccentric, connecting rod and inside rocker arm are within the column. The revolving eccentric causes an up and down motion of the connecting rod (arrow *A*) which in turn causes an oscillating motion of the feed rocker arm (arrow *B*) also of the feed operating link (arrow *C*) and the pawl carrier (arrow *D*).

In the shaper illustrated in Fig. 63, the feeding mechanism is operated by a crankpin (36). In this machine the oscillating movement of the pawl carrier is constant, the amount of feed being regulated by turning the knob (39) which exposes one or more teeth to the action of the pawl.

In the older shapers it was necessary to adjust the feed operating link (connecting rod) between the crankpin and the pawl carrier every time the work table was raised or lowered because of the variable distance between them. In modern

shapers this is unnecessary and the ingenious devises which obviate this nuisance are interesting. See (38, Fig. 63), for one example, and the telescopic friction devise shown in Fig. 70 for another example.

TOOL HEAD. VERTICAL AND ANGULAR DOWN FEED

63. The tool head (Fig. 71) is designed to hold the tool and also for the purpose of adjusting the tool for the desired cut. A graduated collar on the down feed screw serves to indicate

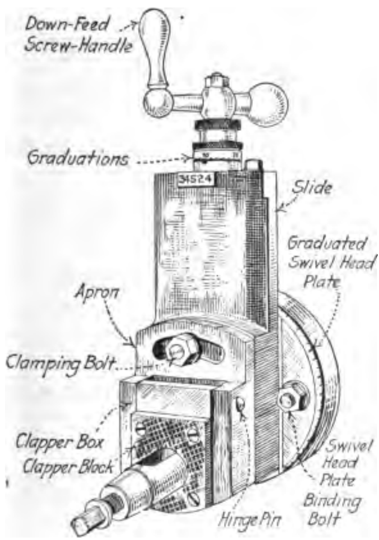


FIG. 71.—Shaper tool head.

the movement of the slide (and tool) in thousandths of an inch. Moreover, the slide and screw permit of a considerable down feed and, because of the swivel construction between the head and ram, this feed may be vertical or at any desired angle in the plane of the swivel. That is, a vertical cut of considerable depth or a fairly wide bevel cut may be taken in the shaper by means of the downfeed. The swivel head

plate is graduated in degrees, and is easily adjusted after loosening the binding bolts.

The cutting tool is held in the tool post securely against the tool block, or "clapper block." The tool block fits snugly to the sides and back of the clapper box and is held by the hinge pin.

During the cutting stroke the tool block is rigidly supported in the clapper box but on the return stroke the block hinges outward slightly on the hinge pin allowing the tool practically to clear the work, and prevents the severe rubbing and consequent ruin of the cutting edge of the tool which would otherwise happen.

By loosening the apron[1] clamping bolt the whole apron may be swiveled through a small arc in either direction, for the purpose of allowing the tool to clear the work when taking a vertical or angular cut. This is more fully explained in paragraph 87, page 103.

The power downfeed is a comparatively recent development in shaper construction but most manufacturers will now furnish this feature at the option of the purchaser (see 44 to 48 inclusive Fig. 63). It is worth while for the reason that power feed is usually more efficient than hand feed.

Questions on Shaper Construction II

1. What is an eccentric?
2. Describe the feed rocker arm?
3. In what direction does the rocker arm move on the forward stroke of the shaper? On the return stroke?
4. How is motion transmitted from the rocker arm to the pawl?
5. Describe the operation of a ratchet and pawl.
6. If the feed screw is $\frac{1}{5}$ pitch (5 threads per inch) every time it makes one revolution it moves the table $\frac{1}{5}$ of an inch. If the notched wheel (ratchet) has 50 teeth, how much is one tooth feed? Two teeth? Four teeth?
7. How is the amount of feed changed?
8. How is the power feed of a shaper reversed?
9. Have the feeds arranged to cause the table to move from right to

[1] *Apron.*—The tool block, clapper box, and hinge pin comprise what is called the "apron."

left and note if the feed operates on the forward stroke or on the return stroke. Reverse the feed (to cut from left to right), does the feed operate on the same stroke as before?

10. What do you change to make the feed operate on the return stroke when the direction of the feed is reversed?

11. Why should the feed always operate on the return stroke?

12. How do you clean and oil the cross rail bearing surfaces?

13. How is the saddle plate bearing adjusted on the cross rail? Why is the provision for adjustment made?

14. Examine the head of the shaper. How is the head fastened to the ram? How may it be swiveled?

15. Set the head over 30°. What angle will the downfeed make with a horizontal surface.

16. Set the head over to make an angle of 30° between the downfeed and a horizontal surface. How much is the head swiveled?

17. What is meant by downfeed in a shaper?

18. How many thousandths does one revolution of the down feed screw handle move the slide?

19. How many graduations are there on the graduated collar? If you move the handle one graduation, how far have you moved the slide?

20. What is the value of the graduated collar on the downfeed screw? Why is it adjustable?

21. Do you read the graduations or the figures, or both? Why?

22. Clamp a tool in the tool post. Is the tool firmly seated during the forward stroke? Can it lift slightly during the return stroke? Why is it so arranged?

23. Where does the hinge pin fit tightly? How does it fit in the clapper block? Where is it oiled?

CHAPTER V

SHAPER WORK

64. Shaper Cutting Tools.—The variety of cuts that may be made in a shaper on any of the metals used in machine construction calls for various shapes of tools. The general shapes are illustrated in the chart (Fig. 74). The similarity of certain of these tools to lathe tools will be apparent; they differ, however, in respect to the clearance angles. The lathe turning tool, for example, is ground with 10° or 12° front clearance, but is set above center to have the effect of perhaps 2° or 3° working clearance.

65. Clearance Angles.—There is no rocker in the tool post of the shaper, hence the tool cannot be adjusted for clearance;

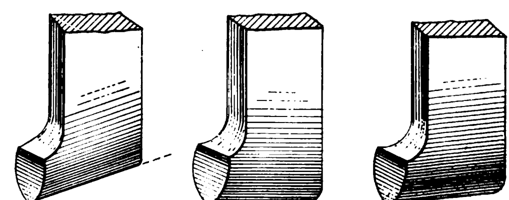


Fig. 72.—Front clearance on shaper tool, (*a*) too much; (*b*) not any, will rub; (*c*) correct, about 3 degrees.

the proper clearance angles must be ground on the tool. The front clearance angle is usually about 3° *c*, (Fig. 72). Since the shaper feed does not operate during the cut as does the lathe feed, a side clearance of 2° or 3° is plenty.

Note.—The elements of a shaper tool or planer tool, that is, the front, side, front clearance, side clearance, front rake, side rake, etc., are in the same relative positions as on a lathe tool, regardless of the fact that the shaper tool when in operation is held vertically and the lathe tool horizontally.

If a shaper tool is given too much front clearance *a*, (Fig. 72,) it will dull quickly because the cutting edge, not being

backed up by metal, crumbles away; if given no front clearance the cutting edge cannot well get under the chip and will merely rub, spoiling the appearance of the work. The same is true with regard to side clearance. Briefly stated, the shaper cut is a straight-away cut and just sufficient front and side clearance is given the cutting edge of the tool that there is no tendency for any part of the tool to rub.

66. Rake Angle.—The shaper tool is usually given side rake of 10° or more depending on the kind of tool and on the hardness of the metal to be machined, but no front rake

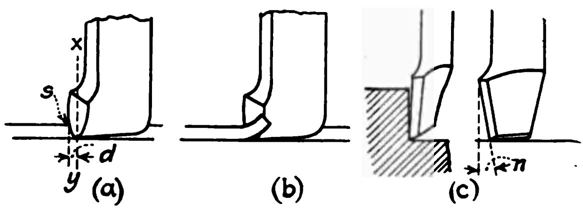


FIG. 73.—Cutting action of tool when machining a plane surface. Note in view (*a*) that line *xy* is parallel to the base of the tool and therefore the tool has no front rake. Note also that since the cutting edge is given side rake, the start of the cut is made at *s* and the distance *d* is traversed before the full depth of the cut is taken; thus the tool enters the work gradually and prevents the shock of the full cutting edge striking the metal at once. The way in which the chip curves is shown in (*b*). In (*c*) is shown a side tool with the cutting edge ground flat to take a finishing cut, say a quarter of an inch or more wide. Note the angle of shear *n* to give an easy start and finish of the cut. A side tool ground in this way is much used in shaper and planer work for finishing cast iron.

except in the finishing tools. The action of a tool when machining plane surfaces is illustrated in Fig. 73.

67. Right-hand and Left-hand Tools.—When setting up a job in any machine it is best if possible to arrange the work and also the tool in such a way that the operator can readily see the cut from his normal position at the machine, that is, from the position in which he controls the machine. For this reason it is customary when taking a horizontal cut on the shaper or planer to start the cut on the side towards the operator, and when shoulder or similar cuts are to be made, to arrange the work so these cuts will come on this side. Many shaper jobs, however, include tongues, grooves, and

angles which involve cuts on both sides of the work. Since in work of this kind it often makes for greater accuracy and speed to *machine in one setting of the work all of the surfaces possible*, it is necessary to have right-hand and left-hand tools.

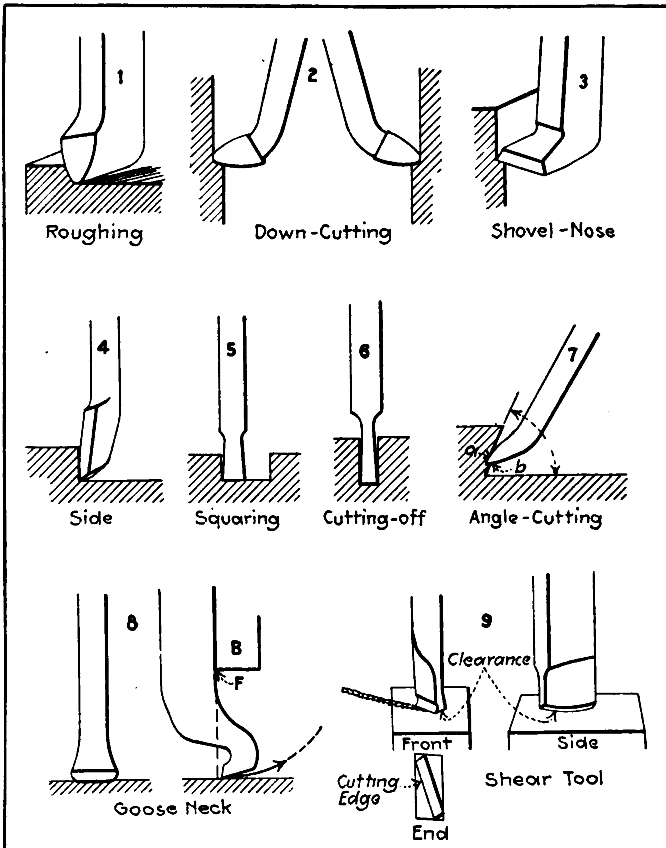


FIG. 74.—Chart of forged shaper tools.

The terms right-hand and left-hand as applied to shaper or planer tools are derived from lathe tools of similar shape. The right-hand tool is most used in the lathe and the left-hand tool is most used for shaper and planer work.

FORGED SHAPER TOOLS

1. *Roughing* or "Shaper Tool."—Similar in contour to lathe turning tool (Taylor). Has side rake but no top rake; amount of side rake, 10° to 20°, depends on the hardness of the metal being cut, the harder the metal the less the rake. For run of shop jobs a very efficient tool for roughing either cast iron or steel. To save the time of changing tools it may be used with a fairly fine feed for finishing smaller surfaces. Used mostly left hand (as shown) but may be ground with the proper clearance and rake and used right hand.

2. *Down Cutting.*—Made substantially in the shape of R. H. or L. H. roughing tool except that it is bent as shown in order to cut down on a vertical surface.

3. *Shovel Nose.*—A very popular and efficient tool for cutting down; cutting edge is widest part of tool; corners are slightly rounded for longer life; cuts down equally well on either right or left side. A tool of this same general shape may be used with a very light chip, coarse feed and a slow speed for finishing horizontal cast iron surfaces.

4. *Side Tool.*—Made either R. H. or L. H. Used for finishing vertical cuts and occasionally for finishing a narrow horizontal cut adjacent to the vertical cut.

5. *Squaring.*—Cutting edge is widest part of blade. Made in any desired width for roughing and finishing sides and bottoms of grooves, keyways, and shallow shoulder cuts.

6. *Cutting Off.*—Similar to lathe cutting off tool, except for front clearance.

7. *Angle Cutting.*—Made either R. H. or L. H. Cutting edges *a* and *b* are ground to the angle required, as for example, 60° as shown. The cutting edge *a* finishes the angular surface, and *b* finishes the horizontal surface. A light chip and fine feed is used for finishing. For roughing the point should be well rounded to give longer life to the tool.

8. *Spring Tool or "Goose Neck."*—For finishing cast iron. Owing to the fact that the cutting edge is back of the fulcrum point *F* of the tool shank in clapper block *B* any spring of the cutting tool is in the direction of the arrow or away from the surface of the work. With this tool there is less tendency to chatter and to "dig in" than with such a tool as the shovel nose.

9. *Shear Tool.*—Used to obtain a particularly high machine finish on steel. It is forged with the blade about 3/16″ thick and twisted 15 or 20 degrees. The cutting edge is ground on a curve (3″ or 4″ radius) and backed-off. With .003″ or .004″ chip and one-tooth feed an excellent finish is obtained, especially if lard oil is used as a lubricant.

68. Tool Holders.—The tool holder and high-speed steel bit have largely superseded the forged tool for shaper work. The tool bit may be ground to the shape required to accomplish the desired result for practically any operation. Figure 75 shows a patented tool holder (Armstrong) which in the smaller size is used for shaper work and in the larger size is very efficient for use in the planer. The construction of this tool holder permits of the tool bit being securely and rigidly held in any one of the five positions shown in *b* so that horizon-

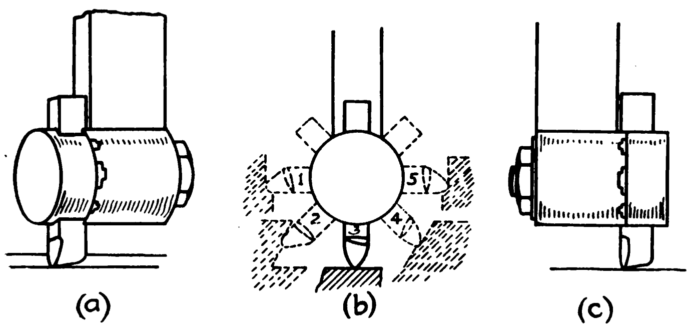


FIG. 75.—Armstrong planer or shaper tool. (*a*) Normal position for horizontal surface, (*b*) Tool arranged for (1) vertical cut; (2) angular cut, (inside angle); (3) horizontal cut; (4) angular cut; (5) vertical cut. (*c*) Tool holder (and tool bit) reversed, brings cutting edge back of shank of tool holder.

tal, vertical, or angular cuts either R. H. or L. H. may be made. Another advantage of this tool holder lies in the fact that for heavy cuts the tool holder may be reversed in the tool post (and of course, the tool bit is also reversed, see Fig. 75 *c*). Since the cutting edge is then back of the shank of the tool the tendency of the tool to chatter or to "dig in" is eliminated. In any case the tool bit should not be allowed to project too ar, as this will result in unnecessary spring.

The lathe turning tool holder and bit makes a very satisfactory shaper tool provided the tool bit is not given too much clearance, especially too much front clearance. Of course, the

position of the bit set at an angle of 20° with the shank of the tool gives a front rake which, while not being desirable, is not prohibitive for light cuts.

The spring tool holder, an example of which is illustrated in Fig. 76 is especially useful in shaper work. Since the body is in the form of a substantial U-shaped spring, this tool holder provides the characteristic feature of the goose neck (8) (Fig. 74). A forming tool of the desired outline may be quickly made for use in this holder to produce a narrow irregular surface (see paragraph 90 page 108).

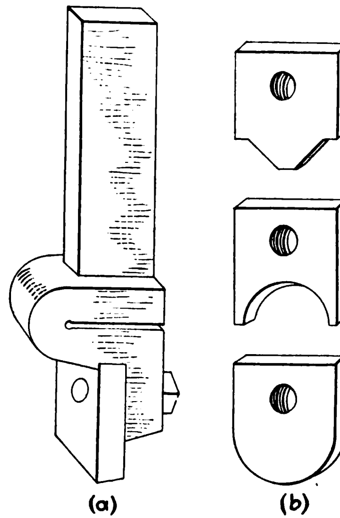


FIG. 76.—(*a*) Spring tool holder and square nose tool. (*b*) types of tools.

Questions on Shaper Tools

1. What is the general shape (contour) of the cutting edge of the most commonly used shaper tool?

2. How much front clearance has a shaper tool? How much side clearance? Why is a rocker not provided with the shaper tool post?

3. Why will a shaper tool dull quickly if given too much clearance?

4. Why is rake ground on a tool? Do the same principles that determine the amount of rake that is given a lathe tool apply to the shaper tool?

5. If a shaper tool has side rake will it cut equally well if fed in either direction? Give reason.

6. What is the particular value of the spring tool?

7. How much rake has a shear tool? Are you able to grind a shear tool on the end of a tool bit?

8. Why is a shovel nose tool particularly good for cutting down? Does it have value for radial facing in a lathe for the same reason?

9. Why is it wise to remove the tool bit from the holder before grinding?

69. Speeds and Feeds.—The reason for machining metal parts (in any machine tool) is usually twofold: (1) to remove surplus metal bringing the work to a given size and (2) to

produce a smooth surface. To accomplish these results at least two cuts, one or more roughing cuts and a finishing cut are nearly always necessary. To operate the machine efficiently to produce these results means a reasonable understanding of the proper speed feed and chip for roughing and also for finishing.

To understand the cutting speed is comparatively easy; it depends almost entirely on three things: (1) the kind of material being cut is a factor, the softer the material the faster the speed at which it may be cut. (2) The amount of material being removed in a given time is a factor, a light cut may usually be taken at a greater speed than a heavy cut; for example, the speed for a finishing cut in steel may often be increased 25 per cent over the roughing speed. (3) The kind of steel from which the cutting tool is made is a very important consideration because a high-speed tool will cut at least double the speed of the carbon steel tool.

70. Depth of Cut and Feed.—The value of any machine tool depends upon its power; the strength and rigidity of its construction; the rapidity and smoothness of its action; its convenience in operation and its accuracy. Modern shapers may be classed as particularly rugged machines, carefully designed and accurately built. Whenever a considerable amount of metal must be removed the shaper should be made to *work* during the roughing cut, that is, the cutting speed should be suitable and the depth of cut and feed should be proportioned to remove as big a chip as the shaper will drive, provided the nature of the work, the way it is held and the strength of the tool will permit. It is impossible to give a rule for the depth of cut or the amount of feed, or for a proportion of feed and chip, but the following suggestions may help the beginner.

First, with a given tool and the given amount of metal to be removed per cut, a coarse feed and lighter chip is not as efficient as a deeper chip and a finer feed for two reasons: (1) the thick chip does not curl so easily and takes more power and (2) the tear in the metal is greater thus producing a

rougher surface. A safe rule to follow is to give as much feed as possible without producing a rough or torn surface, and then all the chip the machine and tool will stand, provided that amount of metal must be removed.

Second, the angle the cutting edge of the tool makes with the surface being cut has a considerable influence on the thickness of the chip. This is illustrated in *a*, (Fig. 77) which represents three chips with the same depth *D* and the same feed *F* but different thicknesses *T* due to the different angles the cutting edge *E* has with the surface of the work. It has been found by experience that a tool with the cutting edge about 20° from the perpendicular *b*, (Fig. 77) with the end well rounded will give the most efficient results in roughing either cast iron or steel.

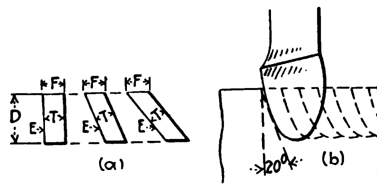


FIG. 77.

The following table of (average) cutting speeds and feeds of cutting tools made of carbon and high speed steels is given for the convenience of the beginner.

TABLE OF SPEEDS AND FEEDS

Cutting tool	Cast iron		Mach ne steel		Carbon steel		Brass	
	Speed	Feed	Speed	Feed	Speed	Feed	Speed	Feed
High-speed steel..	60	1/12	80	1/16	50	1/20	160	1/20
Carbon steel......	30	1/16	40	1/20	25	1/25	100	1/20

The usual practice is to run the shaper too slowly. It is well for the beginner to calculate the number of strokes necessary to give the proper cutting speed for the work at hand until he gets accustomed to seeing the shaper move fast enough.

71. Cutting Speed Calculation.—The calculations for cutting speed for shaper work are more involved than for lathe or drill press work for the reason that the shaper cuts only

during the forward stroke and further, the return stroke is faster than the cutting stroke.

Given the ratio of return stroke *time* to cutting stroke *time* as explained in paragraph 59, as 2:3, the sum of the terms of the ratio equals 5 and $\frac{2}{5}$ of the time equals the *time* of the return stroke and $\frac{3}{5}$ of the time equals the *time* of the cutting stroke.

Given the length of stroke in inches and the number of strokes per minute, their product gives the number of inches cut during one minute of the machine's operation. Since cutting speed is expressed in feet this must be multiplied by $\frac{1}{12}$ to reduce to inches. As noted above the actual time of cutting this distance is $\frac{3}{5}$ minute. Therefore since distance divided by time equals rate, divide the distance (in feet) by $\frac{3}{5}$ (*i.e.* multiply by $\frac{5}{3}$) and the result will be the cutting speed. Instead of multiplying in every problem first by $\frac{1}{12}$ and then by $\frac{5}{3}$ it will be quicker to multiply by .14 which amounts to the same thing ($\frac{1}{12} \times \frac{5}{3} = .14$ approximately). Hence the following:

RULE I.—To obtain cutting speed, *number of cutting strokes* and *length of stroke* being given:

Multiply the number of strokes per minute (N) by the length of stroke in inches (L) and the product by .14. Formula: $.14NL = \text{C. S.}$

Example.—Length of stroke 8″. Number of strokes per minute 30. What is the cutting speed?

Solution.—$8 \times 30 \times .14 = 33.6$.

RULE II.—To obtain the number of strokes necessary, required cutting speed and length of stroke being given:

Multiply the cutting speed by 7 and divide by the length of the stroke in inches. Formula: $N = \frac{C.\ S. \times 7}{L.}$

(*Derivation.*—From Rule I, $.14\ NL = \text{C. S.}$, or $N = \frac{C.S.}{L \times .14} = \frac{C.S.}{L} \times \frac{1}{.14} = \frac{C.S. \times 7.2}{L}$ and for practical purposes $N = \frac{C.\ S. \times 7}{L}$ is near enough.)

Example.—Length of stroke 8″. Required cutting speed 33

feet per minute. How many strokes per minute will be necessary?

Solution.— $\frac{33 \times 7}{8} = 30$ (about).

Questions on Speed, Feed and Chip

1. The proper cutting speed for a given job depends on three things. What are they? Give an example of each.

2. What is a safe proposition to follow concerning the feed and chip?

3. How would you grind and set a tool for roughing cast iron? For roughing steel?

4. About what cutting speed will be practical to start with on cast iron? Is the tool you are to use carbon steel or high-speed steel?

5. May it possibly be wise before long to change to a faster speed? To a slower speed? Give reasons.

6. How many strokes per minute are necessary to give the required cutting speed?

7. Do you suppose a machinist would use a formula to calculate the number of strokes necessary? How would he go about it? Of what value is the formula to the beginner?

72. Holding the Work.—Most shaper work is held in a vise which is bolted to the top of the table. However, the vise may be removed and work which is too large or otherwise impracticable to hold in the vise may be bolted to the top or side of the table, or to an angle plate or any special plate or other holding device fastened on the table. The cuts Figs. 78, 79, 80 and 81, show typical shaper set-ups.

73. The shaper vise is illustrated in Fig. 63 (Nos. 24 to 27). The body may be swivelled on the base plate to any angle desired, graduations in degrees showing the angular setting. This swivel feature is often useful for beveling ends, planing adjacent faces at other than 90° etc., but most of the work is done with the vise jaws either parallel with or at right angles to the direction of the cut. The shaper vise is especially strong, the jaws are long and deep, and the adjustment is sufficient to take work of a considerable width. The jaws are left soft and great care must be taken when clamping work to prevent them from being scored and dented. An auxillary rocker jaw is furnished for securely holding tapered pieces.

FIG. 78.—Planing a dove-tail slide bearing. Note the set over of the head and also of the apron.

FIG. 79.—Planing a keyseat in a pulley. (The pulley is held in a milling vise gripped in the shaper vise.)

FIG. 80.—Using the shaper centers.

FIG. 81.—Shows universal table.

74. Angle plates, (Fig. 82), are of any size required, and are usually iron castings. An angle plate is composed of two members or wings, the outer surfaces of which are machined flat at an angle (usually 90°) to each other. When in use one

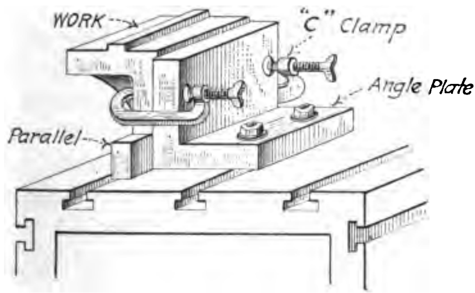


FIG. 82.—Work clamped to an angle plate.

surface is bolted to the table and the work is fastened to the other surface. Some angle plates have one of the inner surfaces finished which permits of work being bolted to this surface when desirable.

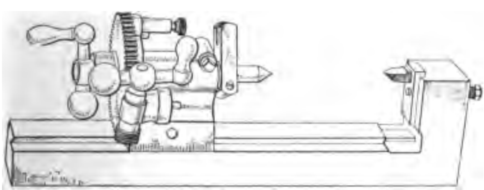


FIG. 83.—Shaper index centers. (*Potter and Johnson.*)

These index centers are designed to be gripped in the vise, and as the base of the vise is circular and graduated, the centers can be adjusted to any horizontal angle. The dead center has a vertical movement for taper work. The live spindle has screw adjustment longitudinally and it is revolved by worm and worm gear, or direct, with the worm thrown out of engagement. The worm gear has a series of holes drilled in its face, and the arrangement of the holes enables square, hexagonal and other common forms to be planed. The adjustable index head has a longitudinal movement for the entire distance between centers. Swing, 4 inches; maximum distance between centers, 8½ inches.

Holes are drilled where necessary for the clamping bolts, sometimes tapped holes are more convenient for the purpose of clamping the work, and often C-clamps are used.

In an *adjustable angle plate* the two members are hinged

and a device is provided for clamping them rigidly when they are set at the required angle to each other.

75. Shaper centers, (Figs. 80 and 83), are very useful for certain curved surfaces that are partially cylindrical but have projecting portions and consequently cannot be turned in a lathe. They may often be used for finishing surfaces of pieces held on a mandrel more advantageously than the work could be done in a milling machine. The construction of the head permits of a variety of indexing[1] operations.

76. Parallels, (Fig. 84), are pieces of cast iron or steel of rectangular cross-section, of considerable length in proportion to their width and thickness, with opposite sides parallel and adjacent sides square. They are used to raise the work to the required height in the vise or to otherwise bolster and level it.

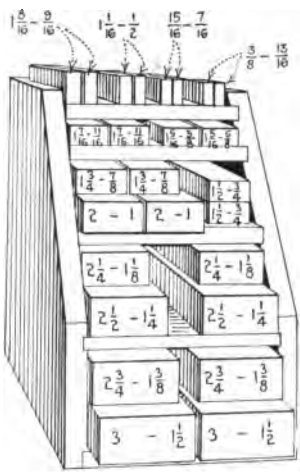


FIG. 84.—Parallels. (*O. S. Walker Co.*)

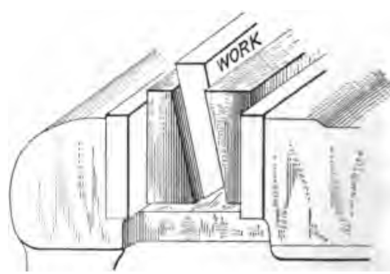


FIG. 85.—Shows application of degree parallels.

Parallels are made in pairs. Two or more pairs may often be used together.

77. Degree parallels (Fig. 85), so called, are similar to regular parallels except that one side of each parallel is planed "out of square" with the adjacent side a certain number of degrees.

78. Hold downs, or grippers (Fig. 86) are thin pieces of approximately triangular cross-section, of the length desired,

[1] *Indexing.*—Turning the work an exact indicated amount on its axis.

¾" more or less) used most frequently to hold thin pieces in the vise. The narrow edge is rounded and the opposite edge is beveled about 2° toward the bottom. This insures the work being held down on the bottom of the vise or on a parallel as the case may be. Hold downs are especially valuable when parallels of the required height to raise the thinner pieces just above the vise jaws are not available. They are very useful also when it is desired to finish only the two opposite surfaces of a piece.

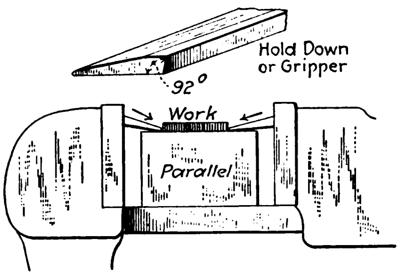


FIG. 86.—Shows action of hold downs.

CAUSES OF INACCURATE WORK

79. Inaccurate Vise or Vise Settings.—In most shops it may be assumed that the shaper vise, as it is arranged, is right enough for the average job, but it may so happen that it is necessary to plane in the shaper a piece which must be *accurate*—square, parallel, and to an exact size—in which case it will probably be advisable to test the bottom of the vise (on which the work rests) for parallelism, and also the solid jaw to make sure that it is square.

80. To Test the Work Seat.—Open the vise wide, be sure the bottom is clean and smooth and with an indicator of any convenient kind (dial test indicator is perhaps best) try the work seat to make sure that it is parallel. If a pair of fairly good sized accurate parallels are at hand they may be arranged as shown in Fig. 87 and four places *A*, *B*, *C* and *D* indicated for parallelism. If *B* and *D* are low it will indicate that the work table sags and probably the saddle gib will need tighten-

ing, or that there is dirt between the vise and the table. If either A and B or C and D are low it will indicate no doubt that the vise is not properly seated on the work table. These faults may be easily corrected to bring the work seat parallel. It may be advisable to shim with paper between the vise and the work table.

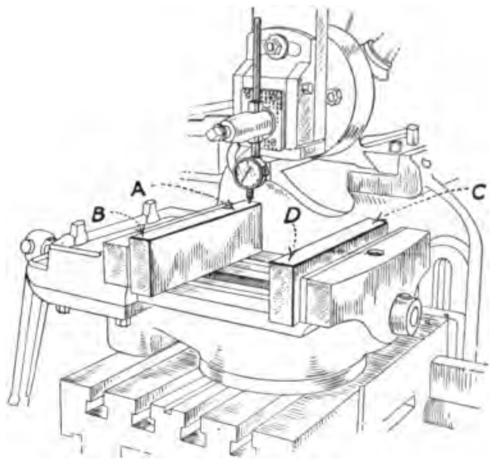


FIG. 87.—Testing the work seat for parallelism.

81. To Test the Solid Jaw.—If the face of either of the jaws of the vise is dented and scored it should be repaired. If the solid jaw is not square with the seat it is impossible to clamp the work against the jaw and plane it square. To test for square takes only a few minutes. Clamp the beam of a square against the solid jaw (with a piece of wood between the movable jaw and the square) as shown in Fig. 88. Arrange the indicator and move the work table the distance A to B. If the indicator registers the same at both ends of the blade the jaw is square. It will be best to try the jaw near each end and in the middle. If necessary, shim the jaw until it is square.

82. To Set the Vise Parallel with Direction of Stroke.—While the graduations on the swivel plate are accurate enough for nearly all purposes, occasionally a cut, for example, a

shoulder, must be made exactly parallel with the edge located against the jaw or the work may be spoiled. To test for this position is very simple. Arrange the length of stroke to about the length of the jaw, hold the indicator in the tool post and slowly run the shaper by hand to note if the indicator registers the same at both ends of the jaw. If necessary to make adjustment clamp the vise lightly and tap with a babbit hammer until the setting is correct, then clamp tight and test once more.

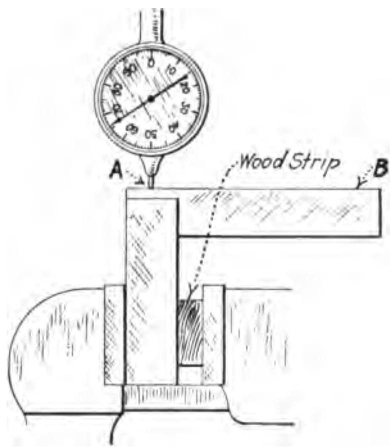


FIG. 88.—Testing the solid jaw for squareness.

82B. To Set the Vise Square with Direction of Stroke.—To test, and if necessary to correct the setting, the indicator is arranged as before but, the vise being turned around 90°, the *work table* instead of the *ram* is moved by hand to show the movement if any of the indicator needle.

NOTE.—An angle plate or similar holding devise when clamped to the work table may be tested for square or may be set square or parallel with the direction of the stroke in exactly the same way as the vise.

83. Chips and Burrs as a Cause of Inaccurate Work.—One of the most frequent causes of damaged or spoiled work is failure on the part of the operator before clamping the work to remove the burrs and clean the chips from the work and also from the holding device whatever it is—vise, fixture, chuck or clamp of any description.

Chips.—Steel chips are worse than cast iron chips, but if either are pinched between a finished surface of the work and the vise jaw, both the work and the jaw will be damaged, and possibly the work will be thrown out of true enough to ruin it.

7

If chips are allowed to get under the parallels, or between the parallels and the work, it is obvious that the work will not seat properly and the finished surface cannot be accurate.

Burrs.—Particularly on steel and wrought metal the last few strokes tend to roll the metal over the corner forming a burr. This burr is more or less difficult to remove, depending a great deal on the sharpness of the shaper tool. If the surface *x*, (Fig. 89) over which the burr is rolled is the next surface to be machined it will cause no trouble, but if surface *x* is to be used as a seat for finishing the opposite side, or if *y* is to be used as a seat the burr must be removed. Sometimes the heavier burrs are removed with a special burring chisel similar to a wood chisel; the lighter burrs are easily removed with a fairly fine file. In either case be very careful not to spoil the corner.

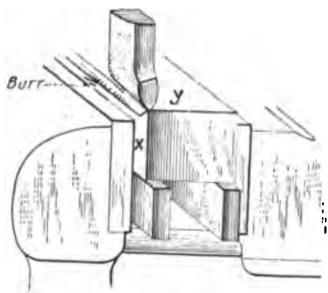


FIG. 89.

Then there is another kind of burr, the kind thrown up by making a nick or dent in a piece of metal. For example, pinching a rough forging or casting between the soft vise jaws without using protecting pieces, will dent the jaws and throw up burrs; likewise pinching a chip between the vise jaw and the finished surface. Dropping a parallel so it strikes the machine may nick it and throw up a burr, and hammering a rough piece down on the parallel will do the same.

It is certain that if the work itself, the holding device, and the parallels are not clean and otherwise in good condition, at least two evils will result, (1) the work will be inaccurate, damaged and possibly spoiled, (2) the parallels, vise, etc., will be damaged.

84. Preliminary Hints on Shaper Work.

1. Keep the machine clean and well oiled.

2. Use the proper wrench or handle, and when not in use keep them where they belong.

3. A vise jaw that is scored and dented and out of true is a disgrace in any shop. A real mechanic is careful. Use brass or copper or cardboard to protect the jaws when clamping the rough surfaces of bar stock, castings or forgings.

4. Parallels should be kept clean, free from burrs, straight, parallel and square. Examine them before using and be sure they are at least clean and free from burrs. Do not hammer a rough piece down on a parallel.

5. Be sure there are no chips on the seating surfaces, or the clamping surfaces of the vise, parallels and work.

6. Carefully remove the burr caused by any previous cut if it will interfere with the proper seating or clamping of the work.

7. Select the proper tool, grind it carefully and oil-stone it. A workman is often judged by the tools he uses.

8. To seat the work use a babbit hammer or babbit ball. Do *not* use a wrench.

9. Do not hammer the work with the babbit, tap it just hard enough to seat it.

10. Tissue paper "feelers" between the parallels and the work are often very useful to determine if the work is properly seated.

11. Do not pinch a thin piece of work too tight or it will buckle more or less and be out of true when the pressure is released.

12. Make sure the thrust bearing at the base of the screw is seated and then loosen the table clamping bolts before attempting to raise or lower the table; some shapers are so constructed that the elevating *screw* will turn without loosening these bolts and then when the bolts are loosened the table will drop.

13. Be sure the top of the table and the bottom of the vise plate are clean and also free from burrs before re-setting a vise that has been removed from the work table.

14. When setting the tool to a surface already finished (or to a size block) be sure the tool block is firmly seated, place a piece of tissue paper under the cutting edge, and then feed the tool down to lightly pinch the paper.

15. When setting up irregular work be sure the head, and also the bottom of the ram will clear the work, during the whole length of stroke and the whole width of the cut.

16. Be sure, at all times, that the tool block works freely and seats properly. Failure to do this has caused a lot of spoiled work.

17. Do not hammer the side of the apron to swivel it. If the edge of the seating surface of the apron is dented and burred it will cause the tool block to bind in the box.

85. The Horizontal Cut.—When the work is fed in a horizontal direction under the reciprocating cutting tool the surface produced is a horizontal flat (or plane) surface. Most of the work done in the shaper is of this description. The length of the stroke is set for approximately ¾″ longer than the work and the position of stroke such that ½″ of this extra length comes at the beginning of the cut to allow the tool block to seat properly for the next cut. In this connection it may be well to state here that if a given piece may be planed either crosswise with a short stroke or lengthwise with a longer stroke, other things being equal it is better to take the longer stroke. To plane, for example, a piece 3″ by 6″ twice as much time will be wasted cutting air when cutting crosswise as when cutting lengthwise. This is illustrated in Fig. 90 where the shaded portion *B* shows air cut with cross-stroke and *A* the air cut with the lengthwise-stroke.

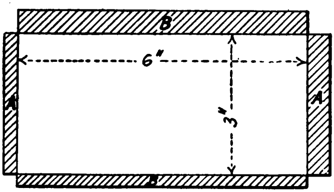


FIG. 90.

This is a little thing? Yes, but if you and I could have the value of the time wasted because of ignorance or carelessness of these little things we'd be *rich*.

The smaller pieces or any pieces that will tend to tip under the pressure of the cut are best held with the vise jaws at right angles to the thrust.

An important point in shaper construction and operation may be emphasized here. The shaper manufacturer takes

the utmost care to have the clapper block fit the box. The bearing surfaces are scraped to provide the best of sliding fits with no shake, the axis of the hinge pin is exactly at right angles and consequently the block hinges freely in the box during the return stroke and is rigidly supported during the cutting stroke. The bearing surfaces should be wiped clean and a very little oil applied at least once a week. If the bearings are allowed to become dry or gummed with old oil or if for any other reason the block does not always seat properly trouble will surely result.

The position of the operator is at the right front of the machine with the speed and feed changes within easy reach. A low stool should be provided. In order that the depth of cut, the action of the tool etc. can be more readily observed, the cut is usually started on the right side—the side nearest the operator, the feed of the table is arranged to move the work toward the operator *on the return stroke* and the left-hand tool is used.

There is practically no difference in roughing steel or cast iron excepting the cutting speed. For roughing plane surfaces of either cast iron or steel the tool illustrated (1) (Fig. 74) or a tool bit ground to a similar shape held in a suitable holder may be used.

Clamp the tool in a vertical position or pointing *a very little* in a direction away from the work, so that if by any chance the tool moves due to the pressure of the cut it will move away from the surface instead of under cutting.

Do not allow the cutting edge to project too far from the tool post—"catch it short"—and clamp it tight. Be sure the tool head slide is not run down too far as this causes weakness and undue strain. It is much better to take time to raise the work table than to allow the tool slide to project below the head or to have the tool project too far.

The tool is adjusted to take the depth of cut desired by means of the downfeed handle, and the work is fed by hand (cross feed) until the cut is started, then, *and not until then,* the power feed is thrown in.

When planing cast metals the edge at the end of the cut should be beveled with a chisel or an old file about 45° practically to the depth of the cut (see Fig. 91) otherwise chunks of the corner will break out below the surface leaving the edge ragged.

Cast-iron scale is hard and gritty. Set the tool to take a chip deep enough *to get under the scale.* If during the cut a portion of the surface is low and the tool rubs on the scale the cutting edge will very soon be ruined. Provided it will not make the work undersize take a deep chip and if necessary reduce the amount of feed but *get the roughing cut under the scale* if possible.

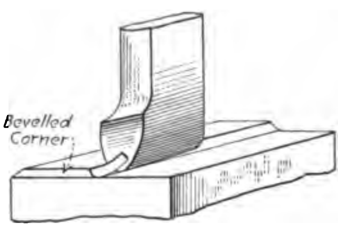


FIG. 91.

The finishing cuts should always be light. For finishing steel or wrought iron a small chip and a fine feed will give the best result. A tool of substantially the same shape as the roughing tool but with a narrower rounded end and a greater rake angle produces an excellent finish, or if desired the shear tool (9) (Fig. 74) may be used.

The accepted commercial machine finish on flat cast iron pieces of any considerable size is a surface that feels smooth and shows feed marks $\frac{3}{8}''$ or more apart. This finish is obtained by the scraping action of a broad square-nosed tool. This tool may be a forging, or the tool bit fitted to any one of a number of kinds of tool holders may be ground to shape. The best tool holder and tool for this purpose is probably a spring tool of a type illustrated in Fig. 76, page 87. It is usually better to use a spring tool so that any tendency of the tool to "dig" will be overcome. With a sharp tool, .002″ to .004″ chip, and $\frac{3}{8}''$ or more feed, a beautiful finish may be obtained. Use a slow speed and feed by hand. If the surface left by the roughing tool is badly torn it may be necessary to take two cuts.

When finishing cast iron, the edge at the beginning of the

cut should be filed slightly bevel so that the cutting edge of the tool will not strike the scale. Keep oil off cast-iron work, even oily finger marks may defeat a good finish.

86. To Sharpen a Square Nose Tool for Finishing Cast Iron (Fig. 92).—Grind the front of the tool flat with 4° or 5° clearance and round the corners slightly, oil-stone the top carefully and set in the tool post as nearly correct as can be judged (cutting edge flat on surface to be finished). Place a sheet of heavy paper on the work and on the paper a good oil-stone. The paper is to keep oil off the work. Raise the tool block, that is, hinge it forward, and bring the oil-stone and paper under the cutting edge of the tool. The tool block is now probably hinged forward 15° or more; raise the slide until it only hinges forward a very little (about 3°). Bearing lightly on the tool rub the oil-stone back and forth between the paper and the cutting edge. Lift the tool, that is hinge it way forward, occasionally and note when it is oil-stoned enough, then remove the oil-stone and paper, and allow the tool block to fall back into place. It is obvious that the tool is sharp and that the cutting edge is parallel with the work and has the proper clearance (about 3°). Feed down carefully to the work and take a very light chip, a coarse feed and a slow speed.

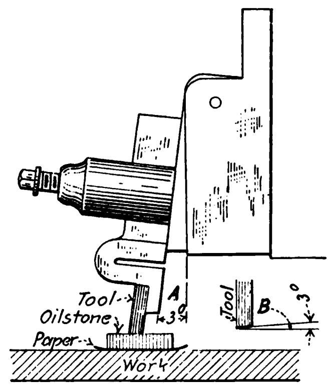


FIG. 92.—If the tool is oil-stoned when hinged forward say 3 degrees as at *A*, then when it is seated, as during a cut, it will have 3 degrees clearance as shown at *B*.

87. Vertical and Angular Cuts.—The downfeed is used for vertical cuts such as finishing the sides of tongues and grooves, squaring shoulders, squaring ends, cutting keyways and occasionally for cutting off. It is used also for angular cuts such as fairly wide beveled edges and ends, and for dovetails.

Except in the case of cutting off or a similar operation, or

where the surface being planed is not much over ¼″ deep (or high) it is very necessary to swivel the apron when using the down feed. This is illustrated in Fig. 93. When the top of the apron is moved in a direction *away* from the surface of the cut, the tool block and tool will hinge in a direction up and *away from* the work during the return stroke. This is true in angular (bevel) cuts as well as vertical cuts (see Fig. 94).

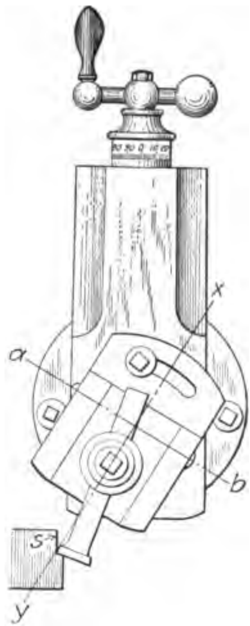


FIG. 93.—Apron swivelled for vertical cut. Axis of hinge pin is in line of *a b*. The direction in which the tool block may raise on the return stroke is in a plane *x y* at right angles to *a b*. If this plane is tipped away as illustrated, the tool will tend to raise in a direction away from the surface *s* and will not rub. If the plane is vertical the tool will rub along the surface *s* on the return stroke.

The set-up for an angular cut with the head swiveled and the apron also set over sometimes appears awkward and wrong. It may help the beginner to imagine the angular cut as a vertical cut and set the apron accordingly. For all vertical or angular cuts it is important to understand and remember the following:

RULE.—Always set the *top* of the apron in a direction *away from* the surface of the cut to be taken.

Although the construction permits of considerable down-feed of the head it is not good practice to use the head with the slide run down much below the swivel plate because in this position it is not as strong and rigid as when backed up by the ram. Sometimes it may be advisable or even necessary, but in no other case than for a finish cut.

Further, when the head is set over for an angular cut and the tool slide fed down too far, it is likely to bring up against the column as the ram slides back. Be careful when setting up to have the slide high enough

at the start for either a vertical or an angular cut, that this weakness or this interference will not result during the cut.

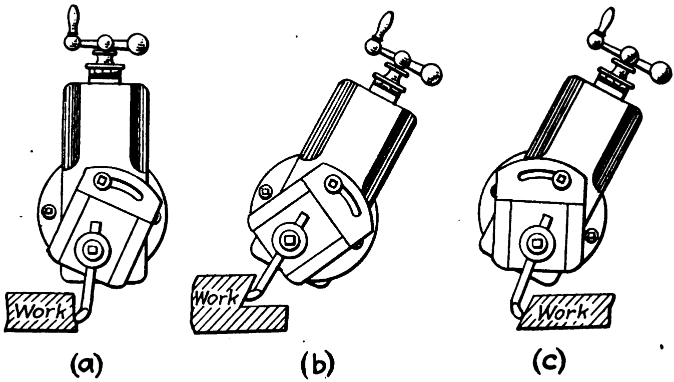


FIG. 94.—Note in each case the top of the apron is set over in a direction away from the surface being cut.

Questions on Shaper Work

1. What precautions should be taken regarding the vise jaws? Why?

2. What are parallels used for? How should they be cared for? Why?

3. Is it good practice to pound rough castings or forgings or bar stock down on parallels? How should they be protected?

4. What are "hold downs" or "grippers?" How are they used? When are they used?

5. State four ways in which the vise may be "out" enough to cause inaccurate work.

6. Explain how you may test the work seat.

7. Explain how you may test the solid jaw.

8. How do you set the vise jaw *exactly* at right angles with the direction of the cut? Exactly parallel..

9. Why is it necessary, in order to do good work, to keep the vise jaws clean?

10. What causes a burr on the work? There are times when it is unnecessary to remove this burr. Explain. If you have several pieces, when do you remove the burrs?

11. How much longer than the length of the cut do you set the length of the stroke? Why?

12. How is the tool arranged in the tool post for a horizontal cut? Why is it tipped? Why is it tipped "a very little"?

13. Frequently one sees the tool slide run down two or three inches below the head. What does this indicate? What is the remedy?

14. When taking a cut in cast iron why should you, whenever possible, plane under the scale the first cut?

15. What is the proper way to take a finishing chip on cast iron?

16. Explain how to sharpen the square nose tool for a shaper cut.

17. How does the clapper block fit the clapper box? Does it shake? Does it bind?

18. Are the bearing surfaces of the block and box smooth and clean? When and how should these surfaces be cleaned and oiled?

19. How may the apron be swivelled? How much?

20. Explain how hammering the side of the apron may prevent the proper seating of the tool block.

21. Clamp a short piece of board vertically in the vise allowing it to project a couple of inches above the jaws. Swivel the clapper box to the right and arrange to have the tool point touch the right hand side of the board. Lift the tool. Does it clear the work? How much?

22. Arrange to have the tool point touch on the other side of the board without changing the position of the apron. Can you lift the tool? What happens? How will you arrange to have the tool clear the work?

23. If the board is tipped 30° from the vertical and the shaper head is swiveled 30° will the same principles apply, both sides of the board, as applied in the preceding questions?

24. Why is the clapper box made so it can be swiveled on the head?

25. What is the rule for setting the apron when taking a vertical cut or an angular cut? Why is this rule important?

26. Why, when cutting in two a fairly thick piece in a shaper is it best to cut half way through from one side and then turn the piece over and make a cut to meet the one already made?

88. To Plane a Rectangular Block or Similar Piece Square and Parallel.—Plane one side, preferably one of the larger surfaces (1), (Fig. 95) then using this surface as a seat against the solid jaw, plane the adjacent side (or edge) 2. If the shaper vise jaw is square and smooth, and if the surface first finished is clean and free from burrs and properly seated against the vise jaw, the second surface planed will be square with the first surface. In order to make sure that the surface first planed is properly seated against the vise jaw, it is customary to use a rod or strip between the movable vise jaw and the work. This will obviate any tendency for the work to change its position, owing to any "give" in the movable jaw.

Next place the second finished surface down on the bottom of the vise or on parallels if necessary, and the first surface against the solid vise jaw as before, with the rod or strip between the movable jaw and the work, tighten the vise and with a babbit hammer tap the work down in the vise to make sure that it is properly seated on the bottom, and plane surface 3. If the vise jaw is square and the tool is sharp, and if care is taken to clean the surfaces of the finished work from burrs and chips, the two edges just planed should be parallel, and both square with the first side planed. Now place the first planed surface down on suitable parallels, clamp the work between the jaws without the rod or strip, and with a babbit

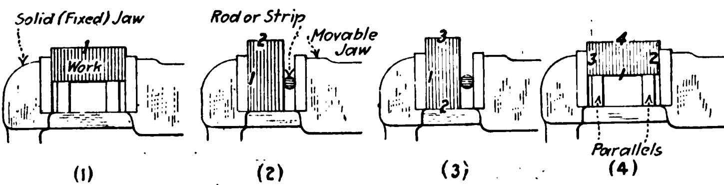


FIG. 95.—The four successive steps in planing the sides of a rectangular piece.

hammer tap (not pound) the work until it is properly seated. If the vise is true and the work is seated on both parallels so that neither parallel can be moved, then it is obvious that the fourth surface will be parallel with the first surface and square with the other two sides.

It is better to seat the work on two parallels rather than one for the reason that it is easier to judge if the work is properly seated. Further, it may be desirable to measure the piece with a micrometer or caliper; this may be more readily accomplished if there is a space between the two parallels or between one parallel and the vise jaw.

89. Squaring the Ends.—The ends may be planed square in two ways, the shorter pieces by taking the cut horizontally across, and the longer pieces by cutting vertically downward. The short piece is set in the vise, either on the bottom of the vise or on a suitable parallel, and a finished edge or side set perpendicular by means of a machinist's square as illustrated

in Fig. 96. Hold the square down hard on the parallel and the piece of work hard against the blade of the square and tighten the vise lightly. Check the setting, tap the work one way or the other if necessary then tighten securely. If this is properly done, and the vise jaws clean and square, the end when planed should be square with the surfaces already planed. To finish the other end it is merely necessary to seat the work on the finished end, tap carefully with a babbit hammer to make sure that it is seated, and finish to the length required.

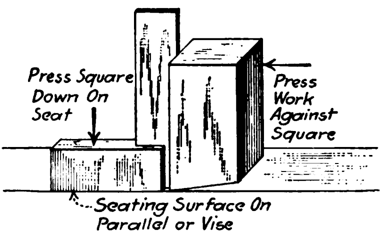


FIG. 96.

If the work is too long to finish the ends in this manner it may be set lengthwise in the vise, letting one end project in a position to be finished by a vertical cut. Use parallels to raise it substantially flush with the tops of the jaws and allow it to project from the end only a short distance. A tool like either (2) or (3), (Fig. 74), may be used in this operation. Tighten the vise securely. Run the tool slide well up toward the top, swivel the apron and adjust the tool. For the reason that the tool will probably have to project some little distance from the tool post in order to take the cut to the bottom of the piece without interference, a feed and chip somewhat lighter than for horizontal planing will be advisable. Care must be taken not to break out the corners at the end of the cut if cast metal is being planed. An excellent finish may be obtained on cast iron with a side tool; have about a quarter of an inch of the cutting edge ground straight and set vertically; take a very light chip, and a half turn of the downfeed screw for feed.

90. Planing an Irregular Cut.—A narrow irregular surface may be finished very efficiently with a forming tool. It will be better to hold the forming tool in some sort of a spring tool holder such, for example, as illustrated in Fig. 76. Even if

only a few pieces are to be planed it will probably be worth while to make a suitable forming tool. When planing a wider irregular cut it usually is customary to lay out the irregular shape on the end of the work and plane to this line. When planing an irregular piece to such a line it is a good plan to rough to within a sixteenth or a thirty-second of the line and then with a file bevel the edge to the line at an angle of 45° or more as illustrated in Fig. 97. With a suitable tool, with a round nose if convenient to use, plane off the bevel. If just the bevel is removed, then the surface is finished to the lay-out line. It is easier to see the bevel and gage the cut than it is to split the line without the bevel. When planing a wide irregular cut of a curved outline the vertical *hand* feed may be employed in connection with the *power* table feed. It is easier and better to feed down than up, therefore, start at the highest

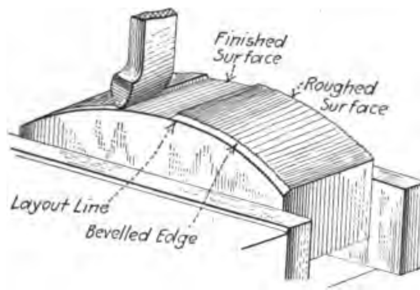


FIG. 97.

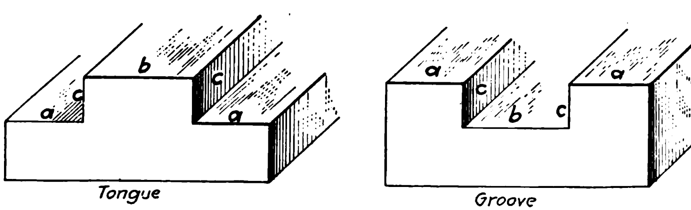


FIG. 98.

part, feed down by hand and feed the table in the desired direction, either by hand or power as desired, usually by power.

91. Planing Tongues and Grooves.—When planing tongues and grooves (Fig. 98) or other shoulder operations, the roughing cut should be made fairly close to the dimension required, using the regular round nose shaper tool wherever convenient.

When finishing, the surfaces *a* and *b* are planed as exact as necessary according to the degree of accuracy desired, but on each of these surfaces there is usually left a thousandth or two for the fitter to file or scrape off. For the distance from surface *a* to surface *b* the graduations on the downfeed screw may be near enough, or if desired a size block (Fig. 99) may be used. If the work is cast iron the tool illustrated in (5) (Fig. 74) may be used without rake for finishing all of the surfaces *a*, *b* and *c*. If the work is steel the finishing tools for the corners (and also for the bottom of the groove) may be shaped like (1) and (2) (Fig. 100). The cutting edges for side and bottom are represented by *x* and *y* respectively. These tools are given 15° or 20° side rake.

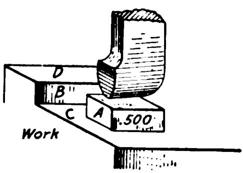


FIG. 99.—Use of size block. *A*, ½″ size block; *B*, shoulder; *C*, finished surface; *D*, surface to be finished ½″ from *C*. A set of gage blocks or "size blocks" is of great value to gage the setting of the tool for shoulders or similar projections. Gage blocks of any desired size, hardened, ground and lapped for extreme accuracy, may be purchased, but for ordinary shaper work a piece of cold rolled steel of the required thickness will answer.

92. Taper parallels or adjustable parallels, (Fig. 101), are useful in gaging the width of a slot or groove; slip one past the other until the slot is filled, then measure over the two with a micrometer. Possibly in a wider groove a straight parallel may be necessary to help fill the width of the groove.

93. Planing Slots Keyways, etc.—A keyway tool looks like a short cutting-off tool and has the same clearance angles.

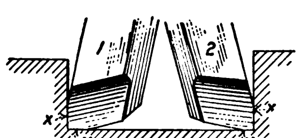


FIG. 100.—Tool bits ground for finishing corners, (1) left hand; (2) right hand.

FIG. 101.—Adjustable parallel. (*L. S. Starrett Co.*)

When planing slots, keyways in shafts, or similar cuts, the average 14″ shaper will carry a tool ¼″ wide in steel or cast iron provided a fairly light chip—.005″ to .010″ is taken.

For a wider slot, two cuts or more may be necessary. If more than two cuts are necessary take the outside cuts to (or splitting) the lay out lines, then remove the metal left between.

94. Taking Cuts Which End in the Metal.—When making a cut which terminates in the metal, (Fig. 102), it is necessary to

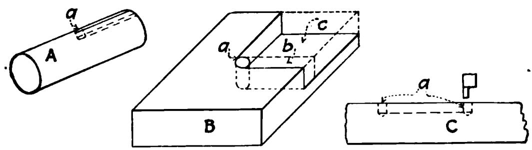


FIG. 102.—*A*, Diameter of drilled hole (*a*) equals width of keyway. In such a job as *B*, first drill hole at (*a*) say 1/4" diameter, next plane slot (*b*) then plane remainder (*c*) the cut ending in slot (*b*). Such a job as *C* requires a drilled hole at the beginning and also at the end of the keyway. Keyways such as shown in *A* and *C* are cut easier in the milling machine, but occasionally must be cut in the shaper or planer.

drill a hole, and in wide cuts to plane a groove, at the end of the cut for the reason that if the chips are not cut off they will remain to clog the cut and soon break the tool. Occasionally it is required to plane a groove, a keyway for example, somewhere between the ends of a rod or shaft *C* (Fig. 103). In such a case, holes should be drilled at the beginning and end of the slot.

NOTE.—Modern shapers are constructed to permit of the end of a shaft extending beneath the ram as far as desired.

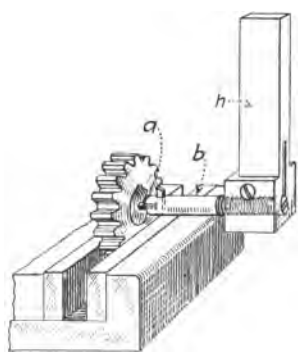


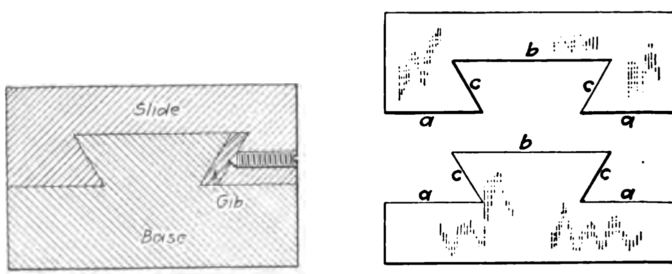
FIG. 103.—Planing a keyseat in a gear.

95. Planing Keyseats.—It is often convenient to use a shaper to cut keyseats in the hubs of pulleys, gears, etc. A forged tool for this purpose is not economical and is not much used. Figure 103 (see also Fig. 79) shows a keyway tool holder that works well. The tool point is held in the bar *b* by a setscrew *a* at the end. The thread on the bar screwing into the holder *h* helps materially in holding. Bars of various lengths may be

used. It is much more efficient to set up the work with the layout on top and feed up as shown because of the tendency otherwise for the tool to chatter and jump.

Draw a radial line on the hub or blank, where it is desired to have the keyseat and set the work with this line perpendicular, using a square. After properly setting the tool adjust the work until the radial line is central with the tool. Take one stroke of the shaper by hand to be sure that there is no interference. When the tool touches the work set the graduations on the feed screw to zero and feed the required depth. On account of the springy nature of the tool use a fairly slow speed and do not feed over .010″ per stroke. If the keyseat is so wide as to make two cuts advisable it is best to lay out the sides of the slot to be cut.

96. Planing Dovetails.—A dovetail slide bearing is illustrated in Fig. 104. To finish such a bearing in the shaper



(a) (b)

Fig. 104.—Dovetail slide bearing

calls for operations which are very similar to cutting a tongue and groove, the chief difference being the planing of surfaces *c*. These surfaces, being angular, call for the set-over of the head and for at least one pair of undercutting tools. The shape of these tools is illustrated in (7) (Fig. 75) (see also Fig. 78). The work should not be disturbed after one side *c* is finished until the other side is finished. This means that a right-hand and left-hand tool will be needed. If considerable metal must be removed, it will probably need a roughing and finishing tool for each side. The surfaces *a* and *b* should be

finished practically as for a tongue and groove, and without disturbing the setting of the work the surfaces *c* and the portion of the surfaces *b* under the overhang may then be roughed and finished. The tool that is used for surface *c* may properly be used for surfaces *a* and *b* provided the tool is not too slender and the surface is not too large. The beginner should pay particular attention to the swivel of the apron. Remember that when *not* properly set it may appear all right and therefore be *very sure* that the *top* of the apron is set in a direction *away* from the surface being planed.

97. Measuring Dovetails.—Probably the greatest difficulty in producing dovetails is in measuring them. When a gib[1] is used between two of the sliding surfaces as great a degree of accuracy is not required in planing as when the two pieces fit together. In either case, however, a smooth cut is necessary, a thousandth or two should be left for scraping, and care must be taken not to "leave too much," and certainly not to "take off too much." It is good practice to lay out the dovetail and if possible it should be scribed on a surface that has been finished. If several pieces are to be planed it will be advisable to make a template of sheet metal 1/8" to 1/4" thick to use for laying out and possibly as a gage.

The table on the next page should prove helpful in making accurate measurements of dovetails to find how much more it may be necessary to plane an angular surface and also to check the finished product. It consists of a series of fixed values for determining the measurements for various angles of dovetails when using various sizes of drill rod.

At first glance the table may appear rather difficult but its use involves only addition, subtraction and multiplication of decimals. In principle it is similar to the three wire method of measuring threads and its application is just as easy.

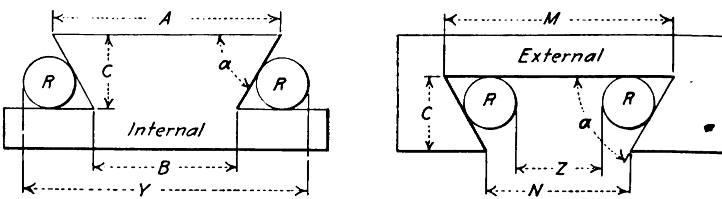
[1] Gib: In machine construction a piece of metal arranged to provide an adjustment for a bearing. In Fig. 104 *a* is shown a cross section of a straight gib between two bearing surfaces and adjusted by a series of screws. Frequently taper gibs are used and the dovetail in the base is made correspondingly wider at one end. Such a gib is adjusted lengthwise to take up the wear in the bearing surfaces.

MEASURING DOVETAILS WITH PIECES OF DRILL ROD

In the table R is the diameter of the drill rod and the values of D and F have been calculated as follows:

$$D = R\left(\frac{\cot \angle a}{2}\right) + R. \quad F = 2 \tan \angle a$$

Various diameters of drill rod	Various values of angle a			
	45°	50°	55°	60°
$R = \frac{1}{4}''$ $D =$	.853	.786	.730	.683
$R = \frac{3}{8}''$ $D =$	1.280	1.179	1.095	1.024
$R = \frac{1}{2}''$ $D =$	1.707	1.572	1.460	1.366
$R = \frac{3}{4}''$ $D =$	2.561	2.358	2.190	2.049
$F =$	2.000	1.678	1.400	1.155



(a) (b)

FIG. 105.—Measuring internal and external dovetails.

RULES

Internal

CASE I.—When the dimension B is given on the drawing.

$$Y = B + D$$

Example.—Angle $a = 60°$, $B = 2\frac{1}{2}''$. Using $\frac{1}{2}''$ drill rod, what should Y measure?

Solution.—$Y = 2.5'' + 1.366'' = 3.866''$.

CASE II.—When the dimension A is given on the drawing it is necessary to find dimension B before proceeding further.

$$B = A - CF$$

External

CASE I.—When the dimension M is given on the drawing

$$Z = M - D$$

Example.—Angle $a = 60°$, $M = 3''$. Using $\frac{1}{2}''$ drill rod what should Z measure?

Solution.—$Z = 3''$, $- 1.366'' = 1.634''$.

CASE II.—When N is the dimension given on the drawing it is necessary to find dimension M before proceeding further.

$$M = N + CF$$

Example.—Angle $a = 60°$, $A = 3''$, $c = 3/4''$. Using $1/2''$ drill rod what should Y measure?

Solution.—First find dimension B thus: $3'' - .750'' \times 1.155 = 3'' - .866'' = 2.134''$.

Then $Y = 2.134 + 1.366 = 3.5''$.

NOTE.—The measurement of Z may be made with adjustable taper parallels placed between the rods (see paragraph 92).

Example.—Angle $a = 60°$, $N = 2''$, $c = 3/4''$. Using $1/2''$ drill rod what should Z measure?

Solution.—First find dimension M thus: $2'' + .750'' \times 1.155 = 2'' + .866'' = 2.866''$.

Then $Z = 2.866'' - 1.366'' = 1.5$.

Questions on Shaper Work 2

1. Given an angular block say 2″ by 6″ and 1″ thick which side should you plane first? Which side will you plane next?

2. After planing the first surface, what objection is there to planing the opposite surface next?

3. Why is the surface that has been planed placed against the solid jaw of the vise?

4. Why is a strip placed between the movable jaw and the work?

5. When planing the third (and fourth) surfaces the use of two parallels, as far apart as convenient, is advisable. Why?

6. How does the arrangement suggested in the preceding question aid in making accurate measurement?

7. How are the ends planed when the piece is short? When the piece is over 6″ or 8″ long?

8. How is short work adjusted in the vise to make sure it is square when planing the ends?

9. Is a coarse feed or a fine feed used in finishing a cast-iron surface in a shaper? For finishing steel?

10. What kind of a tool is used for finishing cast iron? For steel?

11. In planing cast metals what precautions should be taken to prevent the metal breaking out at the end of the cut?

12. Why is it necessary to get under the scale when cutting cast iron?

13. What is a forming tool? Why is a spring tool holder excellent for holding a forming tool?

14. How is a comparatively narrow irregular surface planed?

15. After roughing out a wide irregular surface how is the edge bevelled? What is the object of the bevel?

16. What kind of a tool is used for finishing the sides of a tongue? The horizontal surfaces?

17. How may the groove be accurately and quickly measured?

18. Strange as it may seem, the cutter for keyseats works better up than down. How do you account for this?

19. When required to cut a keyway in a shaft a certain distance why do you first drill a hole at the end of the keyway?

20. What tool is used for finishing the angular surface of a dovetai'

THE PLANER

CHAPTER VI

PLANER CONSTRUCTION

98. Introduction to Planer.—The function of the planer is the production of flat surfaces on work that is too large or otherwise impracticable or impossible to machine in the milling

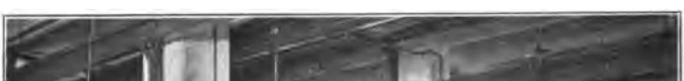


Fig. 106.—Typical shop view of small planers. (*Courtesy Taft-Pierce Mfg. Co.*

machine or shaper. The work is fastened on the work table or "platen" which has a reciprocating motion past the tool head. The tool cuts only on the forward or cutting stroke of the

planer platen and is held stationary except for the feeding movement. The feed may be in a horizontal direction across the top of the work by reason of the movement of the tool head along the cross rail, or in a vertical or angular direction through the downward movement of tool head slide. The operation of the feeds will be explained later.

The single point cutting tool produces a more accurate surface and a surface much better adapted to the scraping operation than a milled surface. Each of the standard machines in the shop has its particular advantages and while the larger sizes of milling machines have taken the place of the planer in certain classes of work, they cannot compete with the planer in the production of flat surfaces that must be finished smooth and true. For example, such machine tool parts as lathe carriages, the bottoms of head stocks and tail stocks, the sliding surfaces of shaper columns and rams, also shaper tables, work tables of grinding machines, milling machines, etc. are planed. For the bases, frames, and heavier sliding parts of such machines as steam engines, locomotives, printing presses, and rolling mill, wood working, and textile machinery, etc. the planer is indispensible.

The general run of planing is very accurate work and calls for a high degree of skill. Planer work should prove very interesting. First-class planer hands are hard to find and consequently are among the best paid mechanics in the trade.

99. Parts of the Planer.—In order to understand certain necessary descriptions which follow it will be advisable for the beginner to become familiar with the names and functions of the planer parts. In a general way the names and descriptions given in the following pages apply to any standard planer of whatever make.

100. Size of Planer.—Planers are classified as to size by the distance between the housings, the distance between the platen and the cross rail at its highest position, and the maximum stroke, for example, the planer illustrated Fig. 107 is 24 × 24 in. × 6 ft.

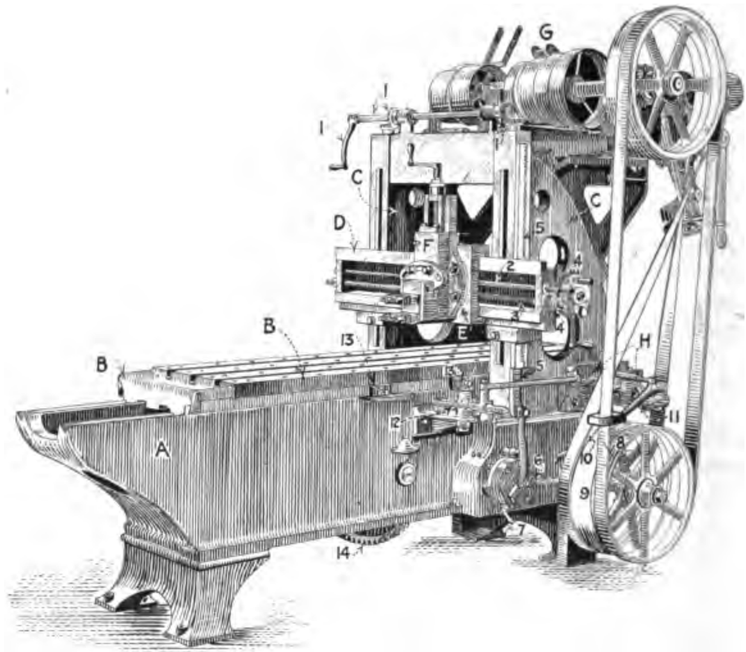


FIG. 107.—Planer. (*G. A. Gray Co.*)

PARTS OF THE PLANER

INDEX TO UNIT NAMES

A. *Bed*, of deep box section, with cross girths to give strength and stability. V-tracks accurately machined and scraped provide sliding ways for the table or "platen."

B. *Table or "platen,"* provided with T-slots and reamed holes for purposes of clamping or otherwise holding the work.

C. *Uprights or "housings" or "posts."* These very rigid supports for the cross rail are securely bolted and pinned or tongued to the bed. The front faces are machined and scraped to be parallel to each other, in perfect alignment, and square with the bed. They are tied together at the top by the "arch" to give greater strength and rigidity.

D. *Cross rail*, carries the saddle and tool head. May be raised or lowered and clamped in the desired position on the finished faces of the housings. (Release the clamps before adjusting.)

E. *Saddle*, supports the tool head, may be moved along the cross rail by hand or power

F. *Tool head,* is firmly fastened to saddle, which is accurately scraped to the cross rail with taper gib adjustment for wear. Has automatic cross feed on the rail, and the tool head slide and screw provide for vertical and angular feed. The feeds may be operated by hand from either side of the machine. Angular position of the head is indicated by graduations in degrees. Downfeed screw is provided with graduated dial reading in thousandths of an inch (for details see Fig. 108).

G. *Speed variator.* For part names see Fig. 114.

H. *Belt shifting mechanism.* For description of principle of mechanism see page 128.

I. Feeding mechanism. Numbers 3 to 7.

J. Driving and reversing mechanism. Numbers 8 to 14.

INDEX TO PART NAMES

1. *Handle, shaft,* and *bevel gears* for raising or lowering the cross rail Motion is transmitted to vertical screws, one back of the face of each upright. It is essential that the cross rail clamping bolts or levers are loosened before attempting to change the position of the cross rail, or the gears and threads will be strained and possibly ruined.

2. *Feed rod* for downfeed, operates through bevel gearing to downfeed screw in tool head.

3. *Feed screw* for cross feed, operates to feed the saddle (and tool head) along the cross rail. Provided with graduated collar reading in thousandths of an inch.

4. *Feed gears,* operate ratchet and pawl mechanism transmitting the feed motion to either the feed rod or the feed screw. (The small gear, "trigger gear," which in some planers encloses the ratchet and pawl may be changed from feed rod to feed screw as desired.)

5. *Feed rack,* operates feed gears (4).

6. *Rocker* on friction, connected by link to feed rack and moves feed rack up and down (friction described, p. 132).

7. *Handle* for adjusting the amount of feed. (Also the position of the nut on the adjusting screw one side or the other of center of rocker slot determines whether the feed shall operate at the end or at the beginning of the cutting stroke).

8. *Loose pulley* for carrying the reversing belt when it is off the tight pulley

9. *Tight pulley.*

10. *Loose pulley* for carrying the driving belt when it is off the tight pulley.

11. *Belt shifting devise* (cam action) operates at the end of the cutting stroke to shift the driving belt off the tight pulley and the reverse belt on. At the end of the return stroke this operation is reversed (explained more fully on p. 128).

12. *Shifter lever* operates the belt shifting devise (11) to reverse the motion of the platen when moved either automatically by means of the dogs (13) or by hand. Also operated by hand to bring the shifting devise to neutral position with both belts on the loose pulleys. In this manner the platen may be stopped without stopping the machine.

13. *Dogs,* adjustable along the side of the platen. The position of these dogs determine the length and "position" of the cutting stroke.

14. *Driving gear* or *bull wheel,* engages a rack fastened to the platen and extending the length of the platen (see "Planer Drive," p. 123).

Perhaps a larger range of sizes obtains in planer manufacture than in any other machine tool except the lathe, but fortunately, in the planer as in the lathe, the principles of construction and operation are practically the same for any size.

To be able to handle a planer, the operator should understand, first, the general construction of the machine, especially the driving mechanism, the feed mechanism, the tool head, and the adjustment of the cross rail which carries the tool head; second, the various methods of clamping the work, which operation, on the planer, probably calls for more skill than in any other machine shop tool; third, how to obtain the cutting action of the tools used which will give the best results.

101. The planer bed is particularly heavy and is designed for strength and rigidity under great weight and heavy duty. The ways for the platen sliding surfaces are planed and scraped. They are automatically oiled from oil wells suitably located. These wells should be filled every week and occasionally should be cleaned. The ways must be smooth and true if accurate work is to be expected. Careless and ignorant operators frequently lose sight of this fact and gritty dust and dirt are allowed to settle on the ways, in fact are often brushed into the ways. Be careful, remember that proper attention directed to the care of machinery marks the *real mechanic* whether he is the operator or the superintendent.

102. The planer platen supports the work. It is provided with accurately finished T-slots for the work holding strips or fixtures and the necessary bolts. It is also provided with reamed holes for stops, poppets, etc. The platen is made of the best cast iron. For the sake of permanency in its finished shape it is rough planed and then allowed to "season" a reasonable length of time before it is finish planed and the sliding surfaces scraped. To make for accuracy the top is planed on its own bed before it is shipped.

The platen is *not* an anvil, nor is it a suitable depository for

half the bolts, clamps, and wrenches in the shop. The holes are accurately reamed to size and care should be taken to keep them round and smooth. Put a little oil on the stops or other planer "furniture" before you wring or tap them into the holes (never *hammer* them in). Two or three strips of old belting placed across the platen protects it when placing heavy castings. After the piece is in position it may be lifted, perhaps with a pry, and the belting removed.

103. The Cross Rail.—The cross rail carries the saddle and tool head. It is adjustable vertically on the finished front faces of the housings by means of two vertical screws; one in each housing. Both screws are moved an equal amount by turning a horizontal shaft arranged above the housings; motion of the shaft being transmitted through bevel gears to each screw at the same time. In the smaller planers the shaft is squared on the end to receive a crank, in the larger planers, 36″ by 36″ and over, a power elevating device is provided.

The cross rail should be clamped rigidly to the housings when in use, and it must be remembered to loosen the clamps when adjusting for height.

The cross rail is of box section construction enclosing the feed rod for power downfeed and the feed screw for the regular cross feed. Great care is taken to have the surfaces on the back scraped to an accurate flat bearing on the housings, and the surfaces for the saddle bearing perfectly fitted and parallel. The elevating screws are arranged to adjust the cross rail equally on each end, but for accurate work care must be taken, especially if the screws are worn or strained, that the rail when clamped is parallel to the platen.

To make sure the rail is parallel to the platen lower it on suitable parallels arranged each side of the platen and then clamp. Another way is to tighten an indicator in the tool post with the point touching the platen and note the reading as the head is run across the rail.

104. The Tool Head (Fig. 108).—In construction and operation the planer head is very similar to the shaper head.

As in the shaper head the vertical adjustment of the tool is made by turning the downfeed screw handle. The *planer head,* however, is always provided with power downfeed, motion being transmitted from the feed rod through a toothed clutch feathered on the rod, thence through two pairs of bevel gears G_1, G_2, G_3 and G_4 to the downfeed screw.

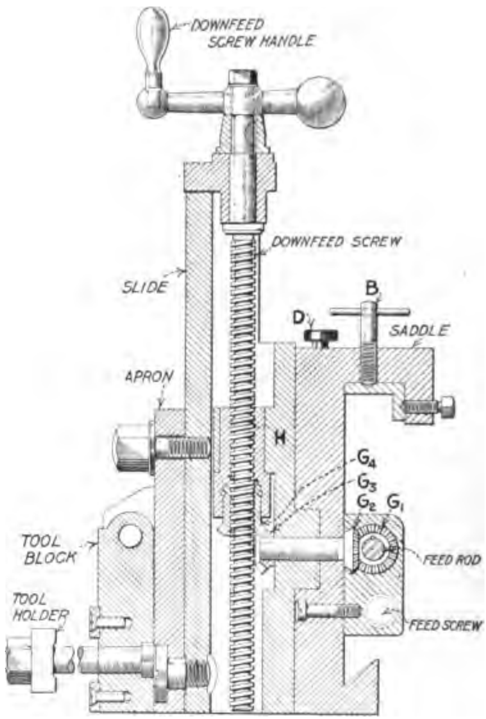


FIG. 108.—Vertical section of planer head.

When power downfeed is to be used the gear G_1 is engaged with G_2 by turning a small knob or lever D.

The tool-head slide is mounted on a swivel plate or "**harp**" H which is fastened to the saddle by two or more clamping bolts. When the bolts are loosened slightly the head may be swivelled through an angle of 90° either side of its vertical or normal position. Graduations in degrees indicate the

angular setting. Similarly as in the shaper head the *apron* may be "set over" either side in order that the tool may clear the work when taking a vertical or angular cut (see p. 103).

A saddle binder screw *B* is provided for holding the saddle rigidly in position when taking a vertical or bevel cut and a tool slide binder screw is provided for holding the tool slide when taking a horizontal cut. Do not forget to loosen these screws when it is desired to move either part. *Remember always that every moving part of a machine should move freely.*

FIG. 109.—Planer with four heads working at the same time on the bottom and sides of a smaller planer platen. (*Courtesy Cincinnati Planer Co.*)

The smaller planers have only one tool head; the larger planers have two heads with independent feed screws. Planers 28″ wide and over may be provided with a side head mounted on the face of each housing. In such planers the finished faces of the housings are long enough to permit of the side heads being run down below the top of the table (see Fig. 109).

105. Planer Driving Mechanism.—The planer platen is driven by means of a gear meshing with a rack which is

fastened on the under side of the platen. In most planers the driving gear is fairly large in proportion, and especially rugged in design, and is often termed the "bull wheel." There are two features of the planer driving mechanism that are especially interesting; (1) the gearing which serves to reduce the speed between the driving pulley and the bull wheel and (2) the mechanism which causes the reversal of the direction of rotation of the bull wheel to give the forward and return movement of the platen.

It may be stated that planer driving mechanisms are divided into three distinct classes: the extended gear train or "bull wheel" drive; the second-belt drive, and the spiral-gear drive.

106. The Bull-wheel Drive.—Figure 110 illustrates the extended gear train or bull-wheel drive as furnished for

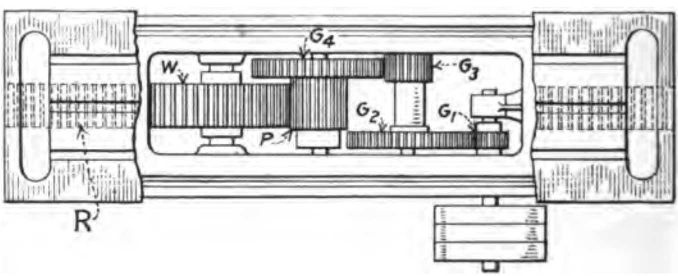


FIG. 110.—Bull wheel drive.

example, on the Gray Planer (Fig. 107). Motion is transmitted from the countershaft to the tight and loose pulleys by means of an open belt for the forward stroke and a crossed belt for the reverse. This motion is further transmitted and the speed reduced by the two pairs of reducing gears G_1 and G_2, G_3 and G_4. The bull-wheel driving pinion P is keyed to the same shaft as G_4 and being engaged with the bull wheel W and much the smaller of the two, serves to transmit motion to the bull wheel at still further reduced speed. The bull wheel engages the rack R which is fastened to the under side of the platen, consequently the platen moves forward or back according to the direction of rotation of the bull wheel.

107. The Second Belt Drive.—Figure 111 illustrates the principle of the second drive belt as applied to Whitcomb Planers. *A* indicates the two loose pulleys and one tight pulley driven from the countershaft. The "second" belt *D*

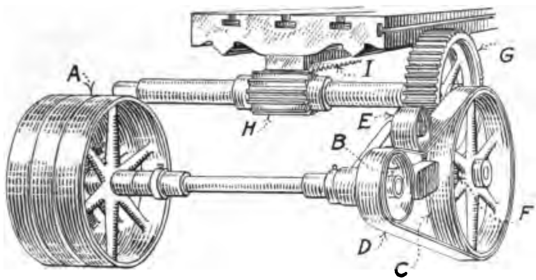


FIG. 111.—Second belt drive. (*Whitcomb.*)

transmits motion from the driving pulley *B*, to the driven pulley *C*. The pulley *E* is an idler which follows up the belt as it stretches and keeps it at the proper tension. The driving pinion *F* is carried by the pulley *C* and engages the large driven

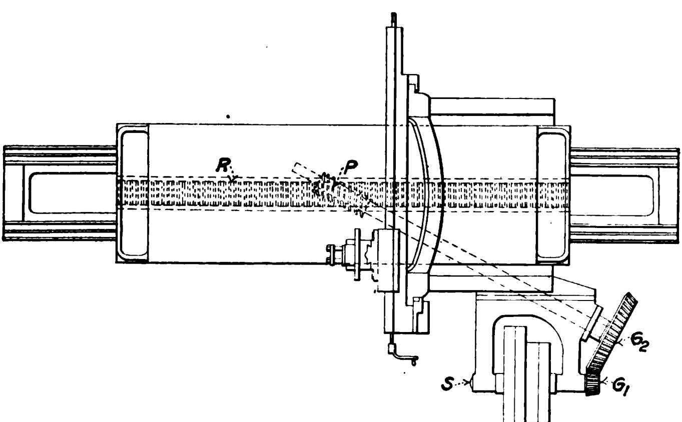


FIG. 112.—Spiral gear drive.

gear *G* which is mounted on the main driving shaft. The main driving shaft carries the gear *H*, which meshes with the rack *I* and drives the platen.

108. Spiral Gear Drive (Fig. 112).—In the planer with the spiral gear drive, motion is transmitted to the platen by means of a spiral pinion P which engages directly with the rack R, and has at all times several teeth in working contact. This spiral pinion is mounted on a shaft which crosses the bed diagonally and motion is transmitted to this shaft from the pulley shaft or driving shaft S through the bevel gea G_2. The pulley shaft is parallel with the line of motic table, consequently the planer may be placed parallel line shaft which feature is often convenient. The continuous semi-rolling, semi-sliding action of the spiral gear drive gives to this type of planer a remarkable smoothness of motion and freedom from vibration.

109. Quiet Running Qualities of Planer.—Great care is taken in the design and construction of planers to insure smooth running and long life. The gears are of ample siz cut from the solid with special cutters made for the particular number of teeth in each gear. The shafts and bearings are proportionally large, in fact, the whole machine is especially rugged. If proper care is taken to keep the ways and other flat bearing surfaces cleaned, all of the bearings, round and flat, properly oiled and the gears well greased, a planer will keep quiet and do its work indefinitely. The boy who has learned to use a piece of waste and an oil can *intelligently* on the machine he is running has gone a long way toward understanding the construction of the machine.

110. Reversing Mechanism.—In any belt driven planer there are two belts, one "open" and one "crossed," which serve in turn to transmit motion from the countershaft to the tight and loose pulleys of the planer driving mechanism. Some planers have one tight pulley and two loose pulleys all of the same diameter, others have two pairs of pulleys of different diameters one tight and one loose in each pair, the larger pulleys for the "cutting" belt and the smaller for the return belt. In either case belt shifters operate automatically when the machine is running, to shift the cutting belt off the tight pulley onto its loose pulley, and the return belt off its

loose pulley onto the tight pulley at the end of the cutting stroke, and the reverse at the end of the return stroke.

The belt shifters are moved by means of a camplate operated through a series of two or more lever arms which are controlled by a slight movement of the initial shifter lever (12, Fig. 107) on the side of the planer. The end of this shifter lever oppo-
andle projects far enough beyond the pivot pin to
arly to the platen, consequently the dog (13, Fig. 107),
ed to the moving platen, comes in contact with the lever, and causes a movement of the lever, a shifting of the belts, and a reverse movement of the platen. This movement will continue until the other dog pushes the lever in the opposite direction. The distance apart of the dogs determines the length of stroke and where they are located on the platen determines the "position" of the stroke.

The purpose of the camplate is to move the belt shifters in such a way that the one belt is completely off the tight pulley before the other is on, to avoid any tendency of the belts to pull against each other.

This feature of construction has the added advantage of making it possible for the operator with a slight movement of the shifter lever, by hand, to run both belts on the loose pulleys thus stopping the platen without stopping the machine. A safety locking pin is provided to prevent accidental starting of the platen. The operation of the belt shifting mechanism is illustrated in Fig. 113.

111. Planer Speeds.—The single speed planer, with a cutting speed of from 25 to 30 feet per minute and a return speed of from two to four times as fast, has been regarded as standard equipment. The single speed planer may still be regarded as suitable in shops having a large amount of uniform planer work provided the speed is arranged in the first place for the particular kind of work. However, the cutting speeds suitable for planer tools are governed by the same general conditions that obtain in other machine tools and therefore multi-speed planers must be recognized as most economical for general work. See List of Tables. p. 397

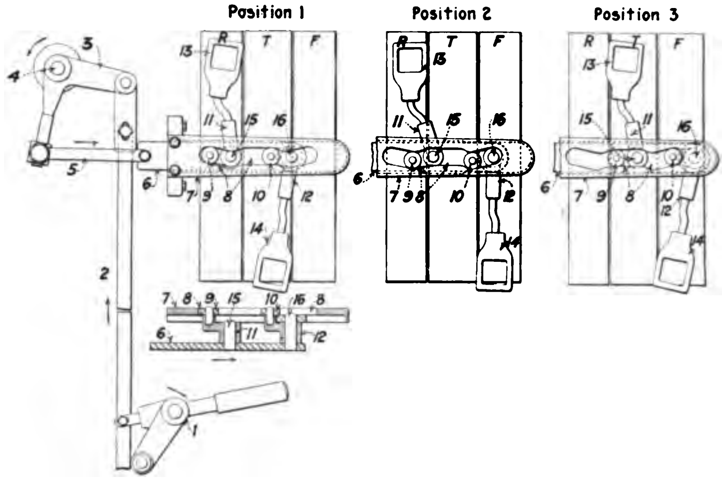


FIG. 113.—Belt shifting mechanism.

The dogs on the side of the planer platen serve to move the lever (1). The lever (1) moves the rod (2) and this operates the bell crank (3) pivoted at (4) and causes a movement of the rod (5) and also the sliding bar (6). Directly over the sliding bar is the cam plate (7) which is fastened to the side of the planer. The cam slot (8) is cut in the cam plate and (9) and (10) are rollers which fit the sides of the slot. The studs on which these rollers are carried are mounted respectively on the short arms of the bell cranks (11) and (12) the long arms of which carry the belt guides (13) and (14). The bell cranks being pivoted on the sliding bar (6) at (15) and (16) move with the sliding bar, and as the rollers (9) and (10) on the short arms of the bell cranks follow the outline of the cam slot the belt guides (13) and (14) are moved in accordance with the movement of these rollers in the cam but a greater distance due to the greater lengths of their lever arms. That is, the parts of the cam slot not parallel with the line of motion of the sliding bar (6) serve to move the short arms of the bell cranks and cause the belt guides to move a considerable distance over the pulleys.

The three positions of the sliding bar.

The cam slot is so made that when the sliding bar (6) is in the "position 1" the reverse belt guide (13) is over the loose pulley *R* and the cutting belt guide (14) is over the tight pulley *T* which is keyed to the driving shaft.

When the sliding bar (6) moves to "position 2" the belt guide (13) remains over the pulley *R* because the roller (8) following the slanting part of the cam slot serves to move the belt guide (13) back as the bar (6) is moved forward. That is, the belt guide (13) is moved back far enough to compensate for the movement of the sliding bar (6). The belt guide (14), however, moves over the loose pulley *F* because the roller (10) following the more abrupt curve in the cam slot throws the belt guide (14) over twice as far as the bar (6) moved. Therefore, in "position 2" the belts are running neutral, that is, both are on loose pulleys.

When the sliding bar (6) moves to "position 3" the guide (13) moves over the tight pulley *T* similarly as when the guide (14) was moved to "position 2," and the guide (14) remains over the loose pulley *F* similarly as the guide (13) did in moving to position 2.

When the direction of the guide plate is reversed the above movements are reversed, thus (14) remains on *F* until (13) is over *R*, at which time (14)

112. Speed Variator.—The various planer manufacturers have developed simple and effective means of quickly changing the cutting speed. The "speed variator" as it is called is usually mounted on a plate on top of the housings. One type of speed variator is illustrated in Fig. 114. Four speeds are obtained through a pair of opposed four-step cone pulleys connected by a belt. One of these pulleys is mounted on a

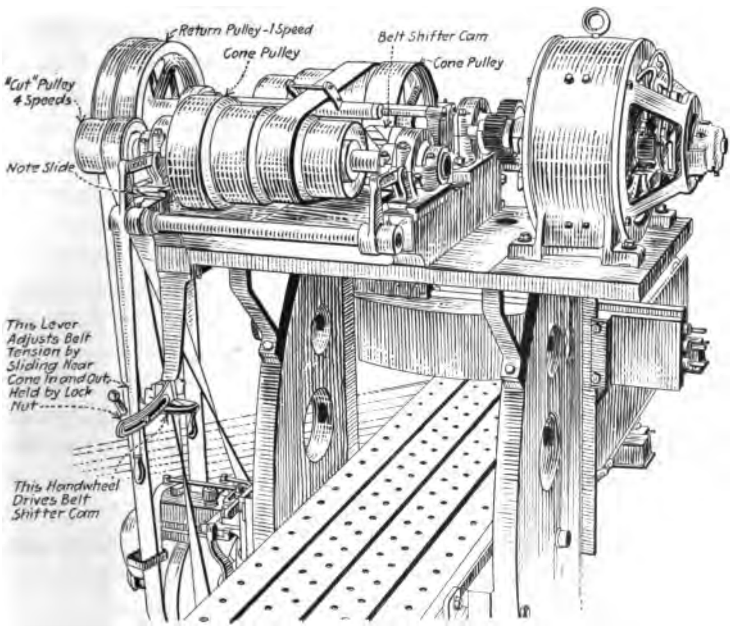


FIG. 114.—Planer speed variator. (*G. A. Gray Co.*)

constant speed shaft which may be driven by a belt directly from the line shaft or by a silent chain or by gears from a motor placed with the variator on the plate. On the end of this constant speed shaft is the return stroke driving pulley. Consequently the return of the planer platen is constant. The other cone pulley is mounted on the variable speed shaft on the end of which is the cutting stroke driving pulley. Consequently four speeds may be given this pulley

The belt is moved from step to step on the cones by a conveniently arranged hand wheel or lever. On the smaller sizes of the planer the variator is usually arranged for the following speeds: 25 feet, 33 feet, 42 feet, 50 feet per minute cutting speeds and 100 feet per minute return speed, and on the larger sizes of planers, 22 feet, 30 feet, 37 feet, 45 feet cutting speed and 90 feet return.

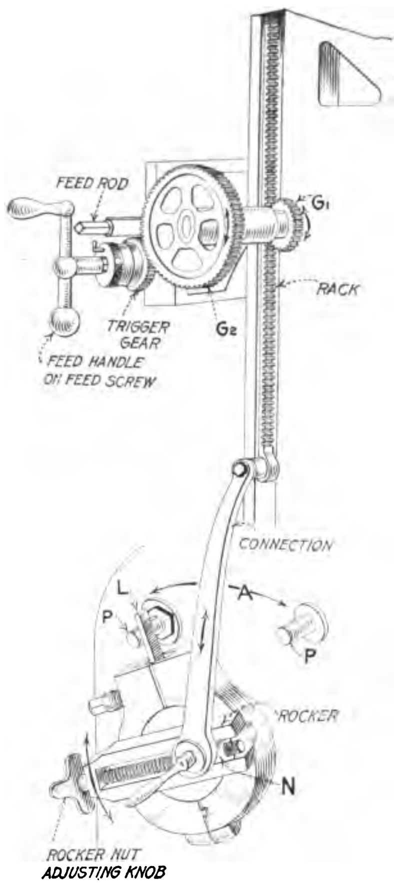


Fig. 115.—Planer feed mechanism.

The larger sizes of planers, however, are best equipped with a variable speed reversing motor directly connected to the initial driving shaft of the planer by means of a coupling. This variable speed drive is especially efficient and with it any one of a wide range of cutting speeds, and also return speeds, is available.

113. Feeding Mechanism. When planing a horizontal surface the feed is accomplished by causing the feed screw to move, thus causing the head to move along the cross-rail. When planing a vertical or an angular surface the feed is accomplished by causing the downfeed screw in the head to move.

The end of the feed screw is squared on the end to receive a handle which is used for adjusting the head to the required position on the cross rail, or for hand feed if desired. Like-

wise the end of the feed-rod is squared and the handle may be removed from the feed screw and put on the feed rod for adjusting the head vertically, if the bevel gears G_1 and G_2 (Fig. 108) are engaged. However most vertical adjustments of the tool are made directly by using the downfeed screw handle, the feed rod being primarily for the purpose of automatic down feed.

A ratchet and pawl mechanism is used in transmitting the automatic or power feeds and in most modern planers this mechanism is contained within a gear frequently called the "trigger gear" Fig. 115A.

In addition to being squared to receive the feed handle both the feed-screw and feed-rod are turned the same size, and keyed, to receive the trigger gear.

By referring to Fig. 115 which illustrates a common type of feeding device, it will be observed that motion is transmitted gear from the rocker, through a connecting link to the rack, thence through the gears (G_1) and (G_2) to the trigger. The trigger gear meshes with gear (G_2) when on either the feed screw or the feed rod.

As will be explained presently the rocker moves through a part of a revolution each forward stroke of the planer and back on the return stroke, consequently an oscillating motion is given to the trigger gear. The amount of this movement is governed by the distance the rocker arm nut N is off center, and whether the motion shall be at the beginning of the forward stroke or the return stroke is determined by the position of the nut one side or the other of the center. Regardless of the length of stroke, the operation of the feed takes place during four or five inches of the stroke. Except on the shorter cuts, it is customary to have the feed operate at the beginning of the forward stroke. Since the feed should take place *before the tool starts to cut*, the stroke is set four or five inches longer than the work.

114. The Feed Friction.—The principle of the friction which operates the rocker for this rapid feed motion during a portion only of the travel of the platen is an important feature of planer design.

The feed friction, one type of which is illustrated in Fig. 116, is usually at the end of one of the shafts of the driving gear train. The hub *H* is keyed to the shaft, consequently is turning in one direction or the other all the time the planer is running. A leather (friction) washer *W* is arranged on each side of the enlarged end of the hub, and the front plate of the

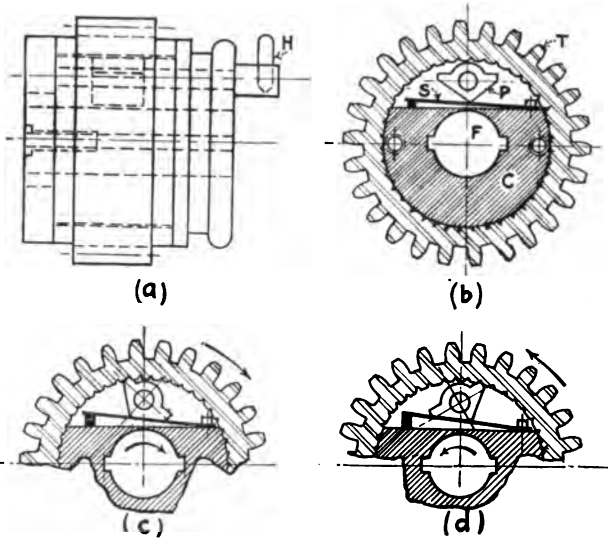


FIG. 115*A*.—Inclosed type of feed gear, ratchet and pawl, or "trigger gear." The pawl carrier *C* is a bushing fitting over the feed screw *F* or the feed rod as the case may be, and fitting freely within a fairly large hole in the gear *T*. A portion of the bushing is cut out to receive the trigger type of pawl *P* and the flat spring *S* that holds it in place. Notches are cut lengthwise through the hole in the gear to form the ratchet teeth. The handle *H* serves to change the trigger to any one of three positions as shown in (*b*) (*c*) and (*d*).

The oscillating movement of the gear *T* serves, in one direction, to move the pawl carrier and operate the feed, and in the other direction, to move the gear one or more teeth over the trigger ready for the next feeding motion. The position of the trigger determines the direction of the movement of the carrier and consequently the direction of the feed. This is shown in (*c*) and (*d*). In (*b*) the pawl is neutral and there is no feed.

friction (which carries the rocker) and the rear plate are pressed against these washers under spring tension by three or more screws. The friction band *B* practically surrounds the hub and the lever *L* is so arranged that when it strikes

each stop P it opens the band a trifle and releases it from the hub.

At each reversal of the driving-shaft motion, the rocker travels through a part of a circle determined by the relative positions of the stop pins P. At this time both frictions on the hub operate and the combination of the two is sufficient to move the feed rack, feed gears, ratchet and pawl, etc., and give the cross feed or downfeed desired. During the rest of

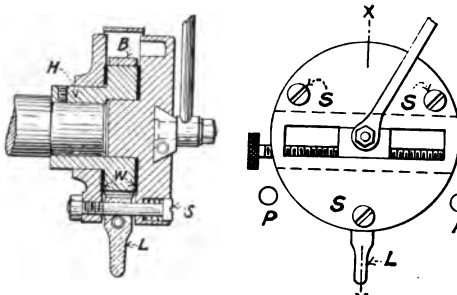


FIG. 116.—Planer feed friction.

the planer stroke the face friction alone operates since the band is released when the lever strikes either stop. The face friction serves to keep the lever against the stop and the band open. On the smaller size planers the combination friction is not necessary and often one friction only is furnished. Such a type is shown in Fig. 115. If even necessary to adjust the friction be *very* sure it is not too tight.

Questions on Planer Construction

1. What is the value of the planer in machine construction?
2. The bull wheel revolves much slower than the driving pulley. How do you explain this? Why is it necessary?
3. What is a rack? How is a rack used in moving the platen?
4. What is the purpose of having a quick return of the platen? How is it accomplished?
5. Why are the holes in the platen reamed?
6. How is the length of stroke changed?
7. The planer does not reverse at *exactly* the same point each stroke. How do you account for this?

8. What are the features of the housings that give them strength and rigidity?

9. How are the front surfaces of housings finished? Why?

10. How is the cross rail clamped to the housings? When is it clamped? When must it be loosened? Why?

11. What is the purpose of the saddle? What is the reason for having a gib between the saddle and the cross rail bearing surfaces? When is the saddle binding screw used?

12. What is the difference between the swivel graduations of the planer head and the graduations on the downfeed screw?

13. Why is it unnecessary to show by graduations the amount the apron is swivelled?

14. Downfeed may be accomplished by turning either one of two handles; where are these handles?

15. Explain briefly the general action of the belt-shifting mechanism.

16. In the planer, the feed operates during the time it takes to move the platen about 6″ and not during the whole stroke. How do you explain this? Explain how the feed would operate if there were no stops on the friction device.

17. Explain briefly the action of the feed rack, feed gears, ratchet and pawl.

18. How tight should the friction be adjusted? Give reason.

19. How is motion transmitted from the ratchet and pawl through the feed rod and four bevel gears to the downfeed screw?

20. How may the platen be stopped without stopping the driving belts? What is the purpose of the safety catch?

21. If the job is at all particular is it safe to assume the cross rail is parallel to the platen? That the head is set square?

22. How could you use parallels to set the cross rail parallel?

23. If suitable parallels were not available how could you use an indicator to test the setting of the cross rail? Why would it be advisable to clamp or block one end of the rail if an adjustment of the other end were necessary?

24. Arrange a tool up side down in the planer head and lightly clamp the frame of a micrometer to the tool, with the barrel projecting downward. Take a reading of the micrometer when the end of the barrel touches the platen (or a parallel on the platen) at each end of the cross rail. How much is the cross rail out of parallel?

25. If you should see a man tugging at a handle to move the planer head or the cross rail, what would you think? Give reason.

26. How much work does the feed friction have to do? How do you tighten the friction? How much?

CHAPTER VII

PLANER WORK

115. Methods of Holding Work.—A great variety of shapes and sizes of work may be machined in the planer, and of course this means that a variety of holding and clamping devices are necessary planer equipment.

Planer "furniture" in common with the work-holding appliances of any other machine tool, may be roughly divided into two classes—general utility tools and special tools. In planer work as in other machine work, the need and value of the special tools, jigs, fixtures, etc., is determined by the quantity of the work. That is, where a great many duplicate pieces are to be planed it is economy to make a fixture in which the work may be quickly set up, correctly aligned, suitably supported and properly clamped. The fixture may be designed to hold a single piece or a dozen or more depending on the size of the work.

On the other hand this work, one piece or a dozen, could, no doubt, be held very well by means of general utility furniture—clamps, stops, angle irons, strips, whichever seems best suited. Certainly one who can intelligently use the regular holding tools will have no trouble asing a fixture.

116. The Planer Vise.—The planer vise, sometimes called the planer chuck is very useful for holding many jobs that are too large or of such a shape as to be impracticable to machine in the shaper. Planer vises are made with plain or swivel bases. Figure 117 illustrates a swivel vise. By loosening the binding screw *A*, (in some vises one and in others two) the body of the vise may be set in any desired position, the angle of the setting being indicated by graduations in degrees. A taper pin, with a squared head for easy removal, is sometimes provided to exactly locate the vise when the

jaws are either parallel or at right angles to the direction of the cut. One jaw of the vise is fixed, and T-slots are provided in the body for clamping the movable jaw *M* by means of the two bolts *B*. The upper face of the body has cross slots to receive the thrust strips *L* held in the backing block *K* which are provided to keep the backing block from slipping after it is located. To fasten the work in the vise, place it against the solid jaw, move sliding jaw up to the work, and tighten the nuts *B* lightly; bring up backing block with thinner section partly under the movable jaw and the thrust strips in the slots; tighten the three set screws *S* sufficiently tight

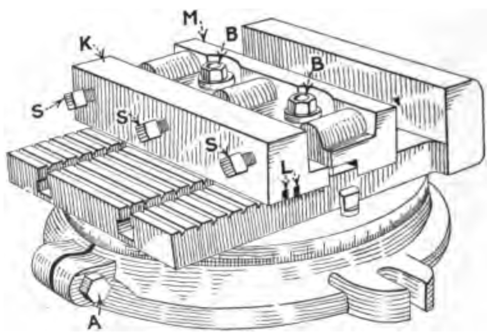


FIG. 117.—Planer vise or "chuck."

to hold the work and then set up the nuts *B hard*. Finally tap the work to make sure it is seated properly. Vise work operations in the planer and shaper are in principle exactly alike. The planer has the advantage of a longer cut. A piece much longer than the vise may be planed if a suitable support, a jack for example, is provided under each of the projecting ends. For information on vise work see page 95.

117. The planer centers (Fig. 118) are comparatively little used as a means of holding work. Most jobs that require indexing can be more advantageously done in a milling machine. There are, however, many occasions in the building of special tools and machines when the planer centers offer the most expedient way or perhaps the only way of finishing

a given flat surface or a given curved surface, or one or more slots in an exact relation to a part already turned or in relation to a hole in which a mandrel may be inserted.

A suitable dog is fastened on the work or the mandrel and the tail is clamped in the slotted driver by a set screw after the work is adjusted between the centers. The work may be adjusted for position by turning the handle which operates the worm and wormwheel and is held in this position by the index plunger. For some pieces it may be advisable to further secure or steady the work by blocks or jacks.

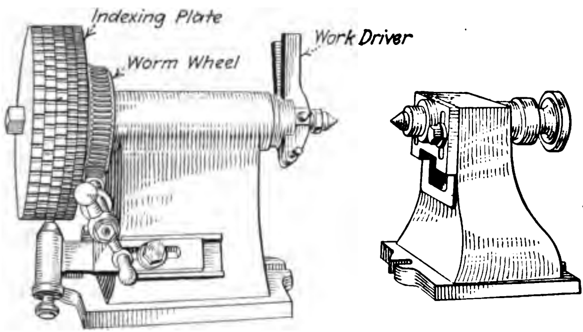


FIG. 118.—Planer centers.

If it is desired to plane a curved surface the tool is set "on center," a distance equal to the radius desired above center, and the work is "fed" for each cut by moving the worm handle a part of a turn.

The tailstock center is inserted in a block, adjustable vertically, for the purpose of planing tapered work.

118. Holding the Work on the Platen.—In ordinary planer practice but few pieces are held by any of the methods previously mentioned; by far the greater proportion of the work that is to be machined in the planer must be fastened more or less directly on the planer platen.

To be able to "set up" the average planer job intelligently the operator must know the tools used for holding and clamping and the principles of their application. For the best method of clamping he must often rely upon his ingenuity.

The success of any job that must be clamped to the table of any machine such as the shaper, drill press, boring mill or milling machine; the face plate of a lathe, or the platen of a planer, depends almost entirely on the manner in which it is clamped, that is, on the knowledge and resourcefulness of the operator. Efficient clamping looks simple enough but it certainly calls for brains.

CLAMPING ACCESSORIES

119. Bolts.—The familiar square head bolt (Fig. 119) is largely used, and for ordinary clamping purposes is satisfactory. To place in position it must be pushed along the T-slot from one end. The T-head bolt offers the advantage of being quickly placed in position as shown. Simply drop the head lengthwise in the slot and turn to the right. This is especially convenient when clamping on the inside of castings which would otherwise have to be lifted over the bolt. Many prefer the tapped T-head which is stronger and in the end probably more economical. If it is required to clamp inside of a casting the stud may be removed and the head pushed along the slot under the casting to the desired position. Studs of various lengths may be used as needed, requiring only a comparatively small number of tapped heads.

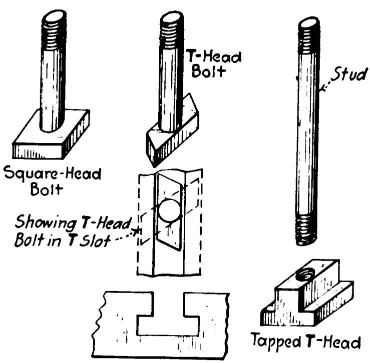


Fig. 119.—Bolts.

120. Clamps.—The *flat clamp* or "*strap*" (Fig. 120) is provided with a bolt hole (usually elongated) somewhat nearer the front end or work end. The front end is usually beveled as shown.

The *U-clamp* may be removed from the bolt without removing the nut. It is also very convenient for purposes of adjustment.

The *finger clamp* or *pin clamp.*—Sometimes a piece of work may be of such proportions that it is inconvenient or impossible to clamp in the regular way and permit the top of the work to remain clear. In such a case it may be admissable to drill one or more holes in each end for the purpose of receiving the turned portion of the clamp. If a finger clamp is not available a short piece of round steel may be used; allow about half an inch of the pin to project and apply a flat clamp.

The *bent clamp* is often useful when it is desired to bring the nut on the clamping bolt below the travel of the tool.

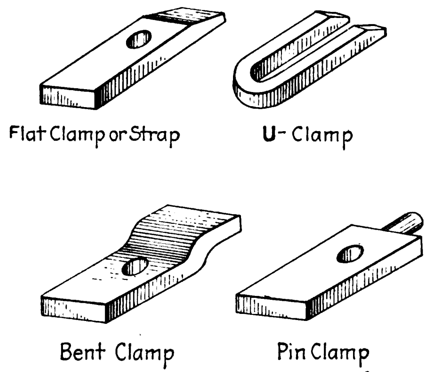


FIG. 120.—Clamps or "straps."

121. Packing Blocks.—Packing under the outer end of the clamp may consist of a piece of handy scrap metal of the required dimensions or if of considerable height suitable pieces of hard wood may be employed. Have the wood of sufficient cross-section to give the needed stiffness and arrange under the clamp so that the pressure will be exerted lengthwise of the grain. Figure 121 shows a step block which is very useful. Both bases are finished and either may be used.

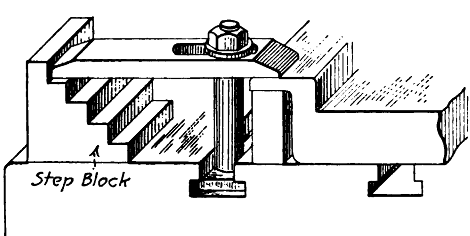


FIG. 121.—Shows use of step block.

122. Shims.—A shim is a piece placed between the table and the work or for that matter between any two pieces or parts for purposes of adjustment or to give support. A shim may be rectangular or tapered slightly, and may be of metal, wood, or paper. Usually, however, a shim is considered as a thin piece of metal, while the heavier pieces are called "packing blocks."

123. Planer Jacks.—For leveling up work or for supporting projections under cutting pressure a jack is an invaluable tool. Figure 122 illustrates a very convenient size. The jack *A* is $1\frac{1}{4}$ in. in diameter at the base and has a range from $2\frac{1}{4}$ in. to $3\frac{5}{8}$ in. Two extension bases *B* and *C* are provided to extend

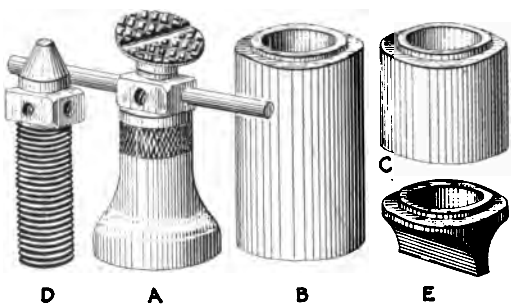


Fig. 122.—Planer jack. (*L. S. Starrett Co.*)

the range to $6\frac{1}{2}$ in. The base *E* is supplied for use when such a shape is desirable. The pointed screw *D* is provided to be used in place of the screw with the swivel cap in certain places where it may be needed, as in a corner.

124. Braces.—Sometimes a job is of such proportions, fairly high and with a comparatively small seating surface, that braces are necessary to assist against the tendency to tip under the cutting pressure. Wooden braces arranged from the work to stops in the table are usually satisfactory.

If, however, a more substantial brace or perhaps an adjustable brace is desired, a piece of pipe of the length required may be provided between the jack *A* and the base *E* (Fig. 122), giving an excellent adjustable brace. A piece of pipe, with a

washer, nut, and bolt or screw arranged in one end for the purpose of adjustment, makes a very satisfactory brace.

125. Planer Poppets, Stops, Toe Dogs.—Planer poppets may be made in either style *A* or *B* (Fig. 123). The hole is drilled and tapped about 10° out of parallel with the platen to give the screw a certain downward thrust when in use. Style *B* may be made of round or square stock as desired.

A poppet made as shown at *C* with the screw set low and parallel with the platen is very useful as a stop for the work.

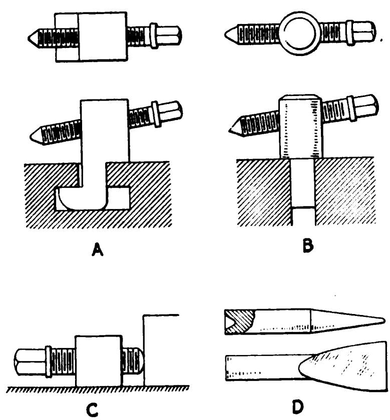


FIG. 123.—*A* and *B*, planer poppets; *C*, stop for work; *D*, toe-dog.

Toe dogs (*D*, Fig. 123) used in connection with the poppets offer an excellent holding device, especially for thin work. To protect the planer table a piece of thin stock, for example, a washer, should be placed under the toe. (See Fig 124 E also Fig 127). A positive stop should nearly always be used when the work is held by toe dogs and great care taken not to buckle the work by unduly tightening the poppet screws.

126. Planer Strips, V-blocks, Angles Plates (Fig. 124) are pieces of metal, usually cast iron, with a uniform cross-section of the desired shape and size and of any convenient length. The base of each is tongued or provided with keys that fit the

slots in the platen and bolt holes or flanges are provided fo the purpose of clamping. Two or more may be used for the

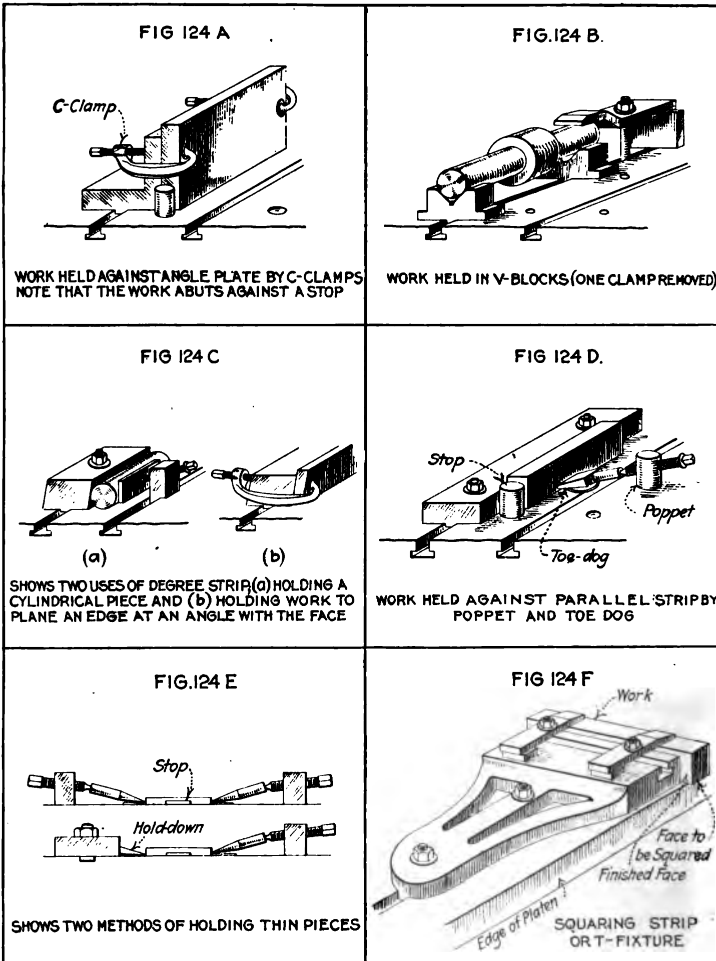


Fig. 124.—Typical planer set-ups.

longer work or when several short pieces are to be planed at one setting.

PRINCIPLES OF CLAMPING

127. Internal Strains.—A very large proportion of planer work consists of machining castings, mostly iron castings, direct from the foundry.

When a casting is poured, the molten metal coming in contact with the surface of the mold chills quickly and forms a skin or "scale" which is much harder and more brittle than the inside. This uneven cooling and the fact that the thin sections of the casting cool more quickly than the heavier parts, causes interior strains. These strains are held more or less in subjection by the scale, and when the scale is removed the casting gives or warps.

This is the reason why the roughing cuts should all be taken before any face is finished. This procedure is not always necessary but should be followed if practicable and must be followed if a certain degree of accuracy is desired. If extreme accuracy is required the casting should be allowed to "season" for a month or more between the roughing and finishing cuts.

128. External Strains.—Practically all metals used in machine shop practice, iron, steel, brass, aluminum, etc. spring under pressure. If a piece is clamped in such a manner that it is sprung or buckled while the cut is taken, when the pressure is released and the piece resumes its natural shape the machined surface will be inaccurate.

For this reason it is very essential if the work does not seat perfectly that it be shimmed or blocked, *particularly under the clamps,* to avoid springing. Usually the sound of a light hammer blow, *before the clamps are applied,* will indicate whether or not the piece is properly seated. A piece may be jacked, or braced, among other reasons to avoid the tendency to spring under the cutting action. Be careful, especially if screw action is used not to set up the brace or jack too tight.

129. Placing the Clamps and the Stops.—A clamp should be properly placed and the packing block under the clamp must be the correct height or the work may become loosened, with probable damage to both work and machine.

A very important point to be observed when clamping work is the position of the clamping bolt. It should be placed as near the work as conditions will permit. By the principle of levers the pressure on the work and on the packing block are inversely proportional to the distance that the work and the block are from the bolt. This is illustrated in Fig. 125.

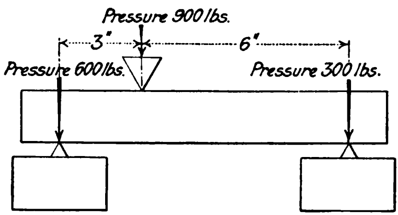


Fig. 125.—Shows a mechanical principle which should be applied when clamping work.

The clamp should have a firm seat on both the work and the clamping block. Packing under the outer end of the clamp

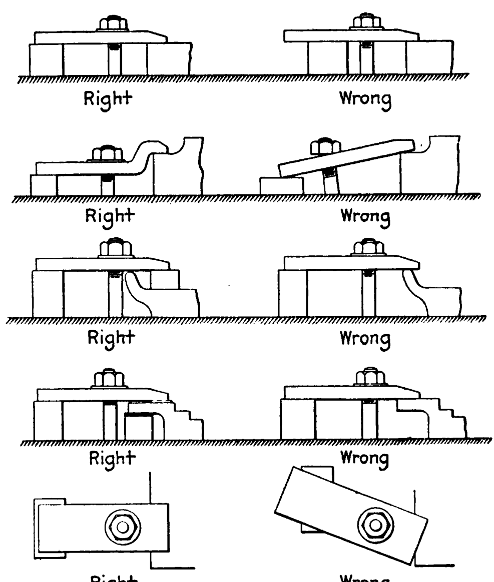


Fig. 126.—Right and wrong applications of clamps.

should be at least high enough to bring the clamp parallel with the surface on which the work rests. It must never be

lower or the clamp will only have contact on the edge of the work. It may be a trifle higher to insure against an edge contact, but if either too high or too low the bolt-head contact in the T-slot, and the nut and washer contact on the clamp are faulty, and the clamping force correspondingly weak.

The clamp must not be placed over a part that will give or spring under pressure until suitable packing is placed under that part.

In Figs. 126 and 127 are illustrated right and wrong methods of using clamps, poppets and toe dogs.

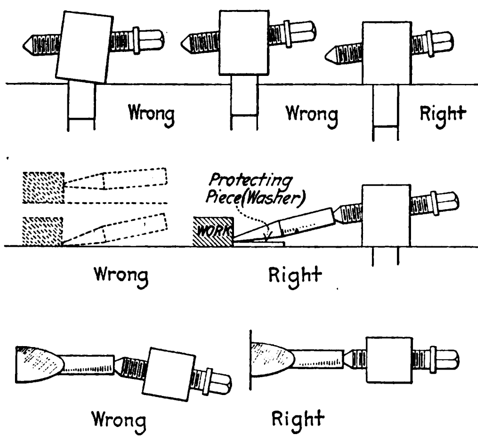


FIG. 127.—Right and wrong uses of poppets and toe-dogs.

The work should be held in the machine in such a way that it will not move under the cutting pressure. In planer work, the thrust of the tool is mostly in a forward direction and comparatively little in a sidewise direction. It is nearly always possible and advisable to use positive stops. Poppets may often be used, but if these are too high a clamp may be bolted to the table; if not high enough possibly an angle plate bolted to the table will do.

The first-class planer hand uses clamps and stops *when*, *where*, and *as* he should. As previously stated, this calls for brains. Size up the work to be done, use *reasoning* when

determining how best to hold it, place the stops, clamps, strips, poppets, toe dogs, whatever is necessary to hold the work, with careful attention to having them placed and adjusted as right as any one could do it. If one does this, the chances are that it is a good set-up and a good set-up is often more than half the job.

130. Clamping Hints.—Do not depend on the accuracy of vise jaws, parallels, angle irons, etc., without testing them.

Do not put a clamp on a finished surface without protecting pieces.

It is very easy to score the table by sliding a rough casting across its surface. Put down protecting pieces of cardboard or similar material. Also do not fail to protect vise jaws, angle irons, parallels, etc., when clamping castings and forgings.

Many pieces are spoiled due to carelessness in cleaning the parts against which the work seats, or is clamped. When a piece is clamped in a vise, or against an angle iron or similar tool, great care must be taken to clean away all chips and dirt.

After a piece is clamped in a vise, tap lightly with a babbit hammer to seat it. Do not tighten the vise again after seating the work as this is likely to lift the work from its seat.

When work is held on a table against an angle iron or similar piece, place tissue paper under each end of the work to determine if it is properly seated. Tap it lightly if necessary.

Use a stop against the work wherever convenient, and avoid unnecessary clamping.

It is very easy to buckle a thin piece and great care must be taken when clamping such a piece in a vise, or when using hold downs or toe dogs.

Form the habit of sighting over the top of the work under the cross rail, and along the sides next to the housings *after* clamping, to make sure everything is clear.

Never use a nut without a washer.

Use the proper size solid wrench to avoid rounding the corners of the nuts.

The thread of the bolt or nut should be oiled occasionally to save time and trouble.

Avoid, if possible, using bolts that are excessively long, and do not in any circumstances use a bolt too short, with only three or four threads catching in the nut.

Particular care should be taken to return clamps, bolts, and all other clamping accessories to the place where they belong. This is only fair to all concerned.

131. Similarity of Shaper Work and Planer Work.—The similarity of the shaper and planer with regard to several of the details of construction, many of the methods of holding the work, and most of the operations and consequently the cutting tools used, serve to make a knowledge of the one a very great help in understanding the other.

It would seem as if the fundamental knowledge and initial experience in these operations should if possible be acquired in shaper work rather than in planer work for the following reasons:

1. The shaper is smaller and easier to handle.
2. Shaper work is lighter and the time taken to set up and make a cut on the average job is much less than in planer work.
3. In shaper work a more extended practice in grinding various tools and in performing a variety of operations common to both machines may be had in a given time and consequently a broader viewpoint of the possibilities and value of these operations and a better understanding of how they are performed may be obtained more quickly in shaper work than in planer work.

When a beginner is assigned to a machine, he should be given an opportunity to study the machine and acquire a reasonable understanding of its mechanisms and the principles and methods of holding, machining and measuring the given job. This, of course, involves more or less general information. About all that may be expected of a text is to supply briefly the fundamentals. If the beginner in planer work has studied this and the preceeding chapter he should have a fair understanding of planer construction and the methods of holding the work on a planer. Now he is ready to start the given planer job. The

principles of the cutting operations in the shaper and planer are practically the same. An understanding of their application in one machine will serve as a general rule in the operation of the other.

Descriptions and explanations of many of the operations common to both planer and shaper have been given in Chapter V and will not be repeated here. Substantially the whole of Chapter V is as applicable to planer work as it is to shaper work. It is suggested, therefore, that the student who is not already familiar with shaper work as therein outlined refer to that chapter in connection with his work on the planer.

In addition to the above statement, references to certain particular pages in Chapter V are made in the following paragraphs on planer work for the convenience of the student and for the purpose of indexing.

132. Planer Tools.—The generally used planer tools are substantially like shaper tools for the kindred operations, the only difference being the size. Descriptions of these tools are given, beginning page 82.

PLANER OPERATIONS

133. Levelling.—As previously stated most work comes to the planer in the shape of rough castings. Frequently it is desirable to scribe layout lines on certain castings to represent the relative positions of the finished surfaces. In many cases if care is not taken in the layout, and in leveling or squaring by these lines in the set-up, the casting will not clean to dimensions required. Sometimes a casting, a plate for example, with apparently plenty of metal for machining, will be so badly warped that care must be taken when setting up for planing the first or working surface. It must be levelled in such a way as to average the corners for height, with due care for later planing the opposite side. It will probably be necessary to shim under two corners, maybe three and possibly all four corners. In addition shims will no doubt have to be placed under certain points where the clamps are to be applied, no matter what kind of clamping devise is used.

The surface gage is an invaluable tool in planer work, for scribing lines, for leveling either a surface or a line, and for gaging.

To plane several pieces (a "string") at one time no doubt saves a considerable amount of time in adjusting and measuring, and very frequently in the cutting operation. If many duplicate pieces are to be planed, a "string fixture" has many advantages in respect to saving time and labor.

134. The Roughing Cut.—When taking a roughing cut the combination of feed and chip should be as great as the nature of the work, the manner in which the work is held, the kind of cutting tool used, and the strength of the machine will permit. When roughing cast iron, care must be taken that the tool does not rub on the scale during any part of the cut. Also in roughing cast iron, in order not to break the corner below the surface at the finish of the cut and thus leave a ragged edge, this corner should be chipped or filed to a bevel of about 45° and to an amount about equal to the depth of the cut.

When roughing, the feeding movement should not take place at the end of the cut because the dragging of the tool on the scale will tend to injure the cutting edge. It should take place at the start of the forward stroke and *before the tool enters the metal* otherwise the feeding mechanism is unduly strained.

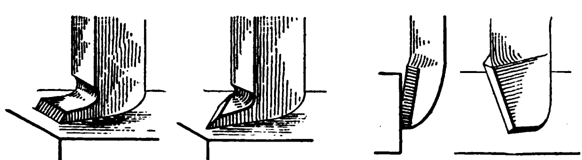


FIG. 128.—Tools for finishing cast iron. *a*, Shovel-nose; *b*, shovel-nose ground for shear cut; *c*, front and side views of side tool.

135. The Finishing Cut.—Usually a better finish is produced on steel with a fairly light chip and a fine feed. The commercial finish of cast iron is produced by using a wide square nose tool with a light chip (.002 in. to .005 in.) and a feed of ½ in. or more depending on the size of the work (see p. 102). That is,

a better finish is obtained on cast-iron work by taking a fairly wide scraping cut than is obtained by taking a deeper cut with a finer feed. This is true on horizontal vertical or bevel surfaces. If the tool tends to chatter, the fault may often be remedied and the chatter marks removed by using a tool which will give a shear cut. In Fig. 128 is illustrated a shovel-nose tool for a horizontal surface and a side tool for a vertical surface each so made as to give a shear cut.

136. Measuring and Gaging.—The test of a plane surface is, first its flatness, second its relation to another surface—its squareness or its other angularity to this surface, or its distance from another surface. The best method of testing for flatness is by means of a surface plate or a suitable straight edge placed on the work, or by turning the work over and placing the surface to be tested on a surface known to be flat. In the latter case, the platen of the planer is frequently used. When the surface is flat there is no "rock" of the work on the platen or no "hollow sound" under a light blow given anywhere on the work.

If a straight edge is used it should be tried in several positions on the surface with tissue paper feelers[1] to determine the straightness and flatness of the surface. Feelers may often be used in a similar way between the corners of the work and the surface plate or planer platen.

Tissue paper feelers are frequently used with a square to test if a surface is at right angles with another surface and may be used with a bevel protracter to test the accuracy of an angular cut other than 90°.

For measuring or gaging the height of a surface, direct scale measurement may be good enough, or a surface gage set to a scale. For measuring the height of a shoulder accurately a height gage or a depth gage is useful. A combination square may be used to test the distance from one surface to another either horizontally or vertically. When a considerable num-

[1] If a straight edge is placed on a surface with narrow pieces of tissue paper between, say one at each end and one in the middle, and any one of them pulls easier than another it indicates that the surface is not flat.

ber of pieces are to be planed with angular cuts, shoulder cuts, etc., it is advisable to have tool-setting gages and work-testing gages as part of the equipment for that job.

137. Memoranda.—Planing Horizontal Surfaces, Vertical Surfaces, Rectangular Pieces, Angular or Bevel Surfaces. Slots, Tongues, Grooves, Keyways, Keyseats, Dovetails, have been described in the chapter on shaper work beginning page 100.

138. Planing T-slots—Use of Tool Lifter.—Figure 129 illustrates a tool for planing T-slots. Many T-slots in the smaller tables, fixtures, etc., are milled, but in the larger castings, they are planed. A slot somewhat narrower than the finished size is planed to the depth required with sides parallel. The lower part of this slot is then widened with the T-slot tools, first one side and then the other as illustrated in *b* and *c*, (Fig. 129), after which the original slot is carefully planed to exact width. When planing a T-slot it is necessary to lift the tool out of the slot before the return stroke, or *to block it so it cannot lift.* Otherwise the tool will tend to lift against the shoulder and will rub so hard as to spoil the work and break the tool. In order to obviate the necessity of lifting the tool by hand each time, a tool lifter, (Fig. 130), may be used. There are a number of kinds of tool lifters, but a hasp or hinge fastened back of the tool as shown works very well. Sometimes an undercut on the edge of a piece of work is advisable. Such a cut may be made in the same manner as the T-slot is cut. Further, the use of the tool lifter is frequently made when taking a

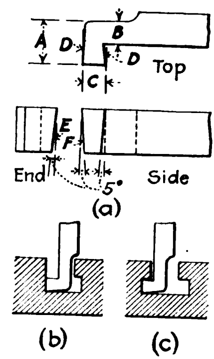
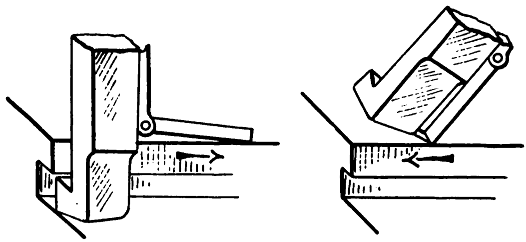


FIG. 129.—Tee slotting tools. Two tools (right hand and left hand) are needed. In the figure (*a*) shows three views of right hand tool, top face is flat (no rake), cutting edge *C* is given clearance of about 5° on front *E*, sides *F*, and also from the front as shown at *D*. As will be observed in *b* and *c*, which show respectively the start and finish of the cut, the width of the tool *A* cannot be greater than the original slot (see *B*) and the width of the neck *b* must be narrow enough to permit the tool to cut its share of the T-slot.

finishing cut over a large surface as it prevents the rubbing of the tool on the work and serves to prolong the life of the cutting edge.



(a) (b)

FIG. 130.—Shows tool lifter, *a*, cutting stroke, *b*, return stroke.

Questions on Planer Work, I

1. What do you understand by the term "fixture" in machine work? What is the value of a planer fixture?

2. Explain in detail the operation of gripping work in a planer vise? How is the movable jaw held down? When is it fastened down hard? How is it backed up?

3. What advantage has a T-head bolt over a square-head bolt?

4. What is the advantage of the tapped T-head?

5. What, in your judgment, is the use of a washer?

6. Describe briefly four kinds of clamps used in holding planer work.

7. What is the difference between "blocking" and "shimming?"

8. What is the advantage of a step block? How would you make a step block with four steps giving eight different heights?

9. Is the height of the block under the clamp an important feature of clamping? Give reason.

10. Is the position of the clamping bolt in relation to the work of any particular importance? Give reason.

11. When is a jack used in setting up a planer job? What precaution should be observed when using a jack?

12. When clamping work down on the platen, what precautions should be taken to avoid springing it?

13. How may a comparatively thin piece be held on the platen and the whole top surface planed at one setting?

14. What is the real purpose of a "stop" for the work?

15. In what respect is the "toe dog" like the hold down or gripper?

16. Manufacturers of high-grade machines take a roughing cut on

tables, beds, frames, etc., and then pile them in the yard for two or three months, possibly longer. What is the reason for this?

17. Why is it usually advisable to take all of the roughing cuts before taking any finishing cut?

18. What do you understand by the term "levelling" in planer work?

19. State three different uses of the surface gage in planer work.

20. Frequently it is necessary to find the low spot on a surface to be planed and then set the tool to get under the scale the first cut. What gage would you use for finding the low spot? For setting the tool?

21. How do the statements in paragraph 63, page 79, apply to the planer?

22. Make a list of the statements in Chapter V that do not apply to planer work.

Questions on Planer Work, II

(For information see Chapter V beginning page 82)

1. What is the difference between a right-hand and a left-hand planer tool?

2. What is the effect of too much clearance on a tool?

3. How do you account for the tendency to grind too much clearance? What is the remedy?

4. What is negative rake? Explain the disadvantage of trying to cut with an edge having negative rake.

5. What do you understand by a shear cut?

6. Is Fig. 74, page 84, a chart of forged planer tools?

7. How do you reason the proper feed and a suitable depth of cut for a given planer job?

8. What are some of the reasons against running the tool head slide down too far?

9. Why is the apron set over when planing a vertical or an angular surface?

10. What is the rule for setting the apron when taking a vertical or an angular cut?

11. How do you prevent the breaking of the edge at the end of the cut?

12. How do you oilstone the cutting edge of a square nose tool?

THE MILLING MACHINE

CHAPTER VIII

MILLING MACHINE CONSTRUCTION

139. Introduction.—Milling machines may be described as the class of machine tools in which the metal is removed by causing the work to be fed against a revolving cutting tool called the milling cutter, which has one or more (usually

FIG. 131.—A typical shop view of milling machines. (*Courtesy Taft-Pierce Mfg. Co.*)

several) cutting edges. The milling cutter rotates with the machine spindle, and, in all milling machines, cutters of a wide range of shapes and sizes may be used. Provision is made for changing the spindle speeds to accommodate cutters of various diameters and suitable automatic feeds for the work table are provided in all except the small (hand) milling machines.

The milling cutter may be made in almost any desired shape, and may be sharpened without destroying its shape. Several cutters may be mounted together on the spindle to machine several surfaces at the same time. These features in connection with the methods available of holding the cutter and the work permit of a ~~variety of operations~~ that make milling machine work one of the greatest factors in rapid production of duplicate parts. The principles of cutting tools, cutting speeds and feeds, holding the work and the cutter, adjustments, measurements, etc. apply to any type or size of machine.

Milling work offers all kinds of jobs from the meanest drudgery in the factory to the most particular and interesting work in the machine shop. (Of all the machine shop tools, only the lathe is comparable to the milling machine in the variety of interesting operations) Most boys have to begin with the simple jobs on any machine, but the ambitious boy who is determined to learn will soon be too valuable to remain with the drudges. Running the milling machine intelligently involves a considerable knowledge of the following things:

1. The construction of the machine, that is, the names of the parts, the location of the oil holes, the operations of the speed and the feed mechanisms and the various other adjustments.
2. The methods of holding the work.
3. The cutters—their names and uses, how they are properly held in the machine and how they are sharpened.
4. An understanding of the proper speeds and feeds for various kinds of work.
5. The construction, use, and value of the various attachments.

A real worth-while understanding of all of these things or of any of them cannot be obtained in a few days or in a few weeks. It cannot be obtained from any book or from all the books that have been written concerning milling machines nor can it be obtained by merely watching the machine run. Practical knowledge comes mostly by doing. Doing a thing correctly means doing it intelligently. Intelligence in any-

thing comes through reasoning and the application of this reasoning to the job at hand. Certain information concerning names and uses of machine parts, holding devices, cutting tools, etc. concerning details of construction of typical mechanisms, details of procedure for typical machine set-ups etc., etc. may be set forth in a book but it is of no particular value if it is not applied. It may be applied in one class of machine or another, in one set-up or another, in any one of a hundred operations. Applying information one may have gained—no matter how—together with one's own reasoning, to the accomplishment of any job is worth-while experience. Knowledge and skill, satisfaction and success can come only through worth-while experience.

The milling machine is a wonderful machine and a milling machine work is especially interesting. No book, no matter how long, can do the subject justice. In these few chapters an attempt has been made merely to explain and illustrate *some* of the interesting features and fundamental principles of milling machines and milling operations.

140. Types of Milling Machines.—There are two distinct types of milling machines, one having a vertical adjustment of the spindle and the other having a vertical adjustment of the work table. Each type is made in many modifications and several sizes. The adjustable spindle machine with its solid work table base is no doubt more rigid for a given size than a machine with the adjustable support for the work table. However these machines are not nearly so easily and quickly adjusted nor so adaptable for a variety of work as the machines having the adjustable work table support. They are much used in manufacturing, but are not often found in tool-making or model-making rooms, or in the machine shop as differentiated from other factory departments. Brief descriptions of various kinds of both types of milling machines follow. Several makes are illustrated. Attention is called to the similarity of typical features of construction. In this connection read the introduction to this chapter again.

141. Milling Machines Having Vertical Adjustment of Spindle.

The Lincoln Type[1] (Fig. 132).—The original Lincoln Milling Machine was built about 1850 by G. S. Lincoln & Co. (Phoenix Iron Works) of Hartford Conn.

It was designed by Francis A. Pratt, then a young machinist and later one of the founders of the Pratt and Whitney Co.

FIG. 132.—Lincoln milling machine. (*Courtesy Pratt & Whitney Co.*)

These machines are used in manufacturing a large number of duplicate pieces. Sometimes an unskilled man or boy can operate several machines after they have been "set up" by a skilled mechanic. That is, after the machinst had adjusted the machines to take the desired cuts, the operator can remove

[1] "This machine is one of the most striking early examples of advance design, as no machine tool has suffered so little change during the succeeding years. . . . No form of milling machine has been made in such large numbers."—F. A. HALSEY: "Methods of Machine Work."

from the machine a piece that has been milled and put in the next while the other machines are running.

The P. & W. Semi-Automatic Milling Machine (Fig. 133) is an adaptation of the Lincoln milling machine. The work table of this very special manufacturing machine is provided with an automatically controlled rapid power traverse, either con-

FIG. 133.—Semi-automatic milling machine with receding table. (*Courtesy Pratt & Whitney Co.*)

tinuous as for the return, or intermitent as when the surface to be machined is not continuous. The rapid traverse and the regular feeds are controlled by adjustable trip dogs. Suppose the machine has been adjusted to mill three surfaces with spaces 3 in. long between them. After the work is tightened in place, and the "feed" thrown in, the rapid traverse

(100 in. or more per minute) operates until the first surface reaches the cutter, when the feed motion slows down to the desired amount per minute and continues until the surface is milled. When the space is reached the rapid traverse operates until the next surface reaches the cutter and so on until the work is finished when the rapid return brings the table back to its original position. Another feature of this machine is the receeding table; before the rapid return operates the table lowers a sufficient amount to clear the cutter thus preventing the work from becoming marred by the revolving cutter.

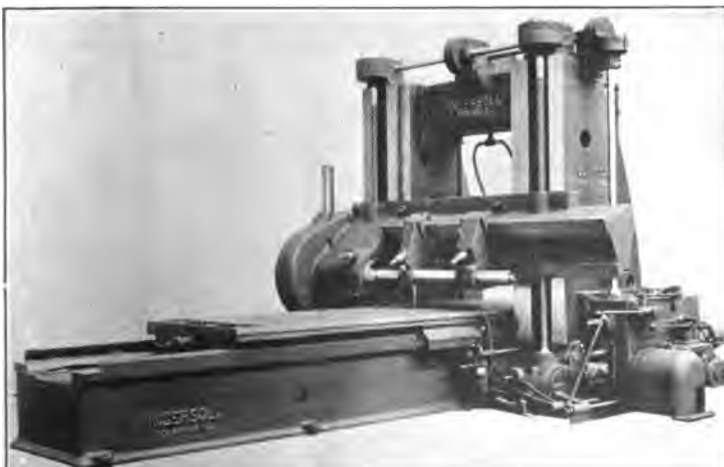


FIG. 134.—Planer type milling machine with horizontal spindle. (*Courtesy Ingersoll Milling Machine Co.*)

The Planer Type (Fig. 134).—This kind of machine is suitable only for large work. It resembles a planer in appearance, hence its name. When a considerable number of pieces are to be machined to an irregular outline a special cutter or number of cutters may be arranged to finish such work much more quickly than it could be done in a planer. Another style of the planer-type milling machine has four independent cutter heads two adjustable on the cross rail and one adjustable

on each upright. Planer milling machines are much used in the manufacture of locomotives, automobiles etc.

The Profiling Machine (Fig. 135).—The profiling machine is practically a milling machine of the adjustable spindle type with the spindle held in a vertical position. The special characteristic of the profiling machine is the guide block or

Fig. 135.—Profiling machine. (*Courtesy Pratt & Whitney Co.*)

template together with a guide pin by means of which the revolving cutter may be made to follow a predetermined outline or profile. The guide block is fastened to the work table a certain distance from the position of the work, and the guide pin and the cutter spindle remain a relative distance apart. The table is fed by hand keeping the guide pin against the guide block, with the result that the cutter will produce on

the work a profile corresponding to the profile of the template. This machine is valuable in the manufacture of pistol or rifle parts, sewing machine parts, etc.

The figure shows a two spindle machine. By means of two spindles a roughing and finishing cut may be taken in one setting of the piece.

142. Milling Machines Having Vertical Adjustment of Work Table.—A large proportion of milling machines are of the type having the work table adjustable for height. The saddle on which the work table rests is supported on a bracket or knee which may be moved vertically on a finished face on the front of the column. The knee may be rigidly clamped in any desired position. This type of machine is classified as to kind as: *Universal, Plain, Hand* and *Vertical.*

The Universal Milling Machine (Figs. 140 and 143).—The Universal Milling Machine was invented in 1862 by Joseph R. Brown one of the founders of the Brown & Sharpe Manufacturing Co. This machine was originally designed for the purpose of making twist drills. It is so constructed that the table may be swiveled to a considerable angle in a horizontal plane to permit of milling spiral (twisted) grooves such as are cut in twist drills, spiral mills, etc.

The work table may be moved longitudinally, by hand or automatically, in either direction, this is called the longitudinal feed or more often "table feed." The saddle is so arranged on the knee that it may be moved transversely by hand or power in either direction; this is called the cross feed. The vertical movement of the knee may be used as a vertical hand feed in either direction and in the larger sizes, automatic vertical feed is provided.

Numerous attachments are built for the universal milling machine which permit of a very large number of distinct operations. It is essentially a tool-maker's milling machine and is one of the most important, most adaptable and most interesting machines in the shop.

The plain milling machine (Figs. 136 and 137) is a simplified model of the universal milling machine. It has largely

displaced the Lincoln type for milling a considerable variety of manufactured work. It is very similar in appearance and construction to the universal milling machine and differs chiefly in that it lacks the swivel table construction. Many of the attachments made for the universal milling machine can be used on the plain milling machine. The cuts show two sizes of this machine.

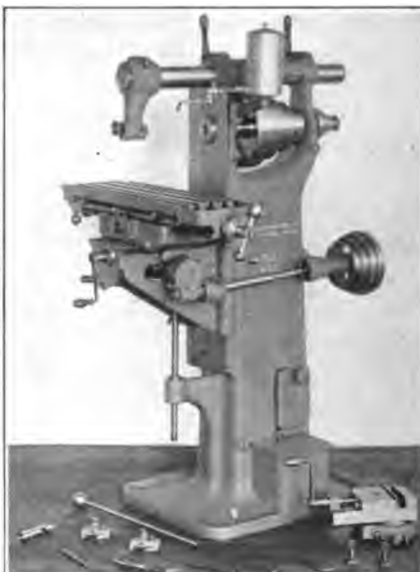


FIG. 136.—No. 0 Plain milling machine. (*Courtesy Brown & Sharpe Mfg. Co.*)

The Automatic Milling Machine (Fig. 138).—This is an adaptation of the plain milling machine. It has the advantages of the plain milling machine such as a wide range of adjustments quickly made, the use of interchangeable attachments, etc. and in addition is largely automatic in operation. The distinctive features of this machine consist of the automatic controls, through the medium of adjustable dogs, of the spindle stop and reverse, and also of the feed motions, intermittent forward as desired and fast reverse.

This machine is designed for rapid production of a quantity of duplicate parts, but may be used if necessary as a plain milling machine.

Set up for maximum production of a given job two fixtures

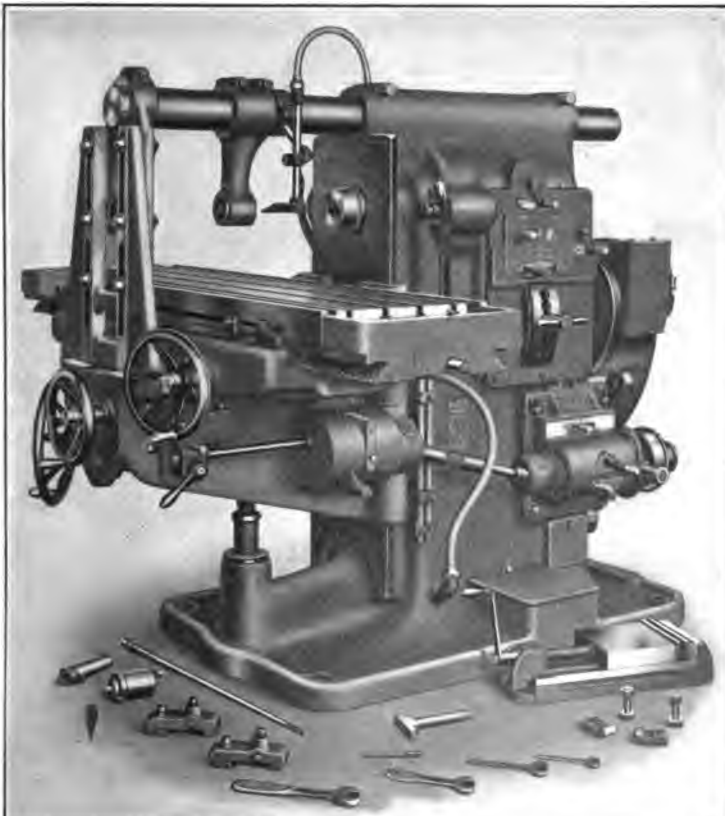


Fig. 137.—No. 5*B* Heavy plain milling machine.
(*Courtesy Brown & Sharpe Mfg. Co.*)

would be used at opposite ends of the table also two cutters arranged to revolve in opposite directions.

While one piece is being milled, the operator loads the other fixture. Directly the piece being milled is finished, the spindle stops and the quick table feed reverse operates until

the work is close to the other cutter at which time this cutter starts in its proper direction and the table starts to feed. The other fixture is then ready and in position to unload and reload.

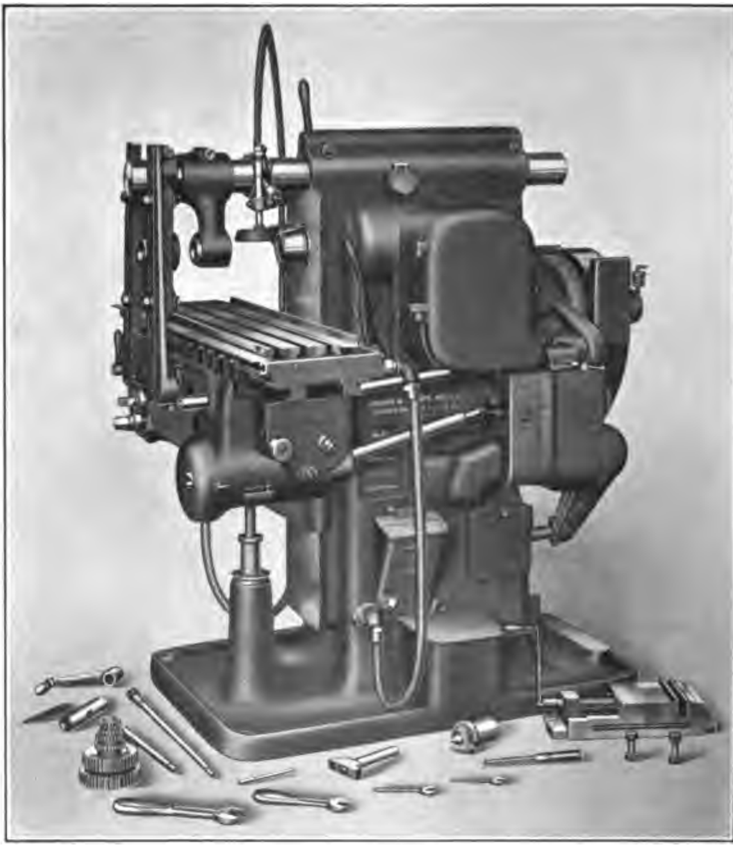


Fig. 138.—Automatic milling machine.
(*Courtesy Brown & Sharpe Mfg. Co.*)

The automatic features are governed by suitable cams and gears similar to other automatic machines.

The hand milling machine (Fig. 139) is sensitively operated by hand by means of a lever or a screw. It is very valuable for

small milling jobs and especially so for a large number of small duplicate pieces.

The vertical spindle milling machine (Fig. 142) is so called because the axis of rotation of the spindle is vertical. Except for the position of the spindle, it is similar in construction and operation to the plain milling machine. For many end

FIG. 139.—Hand milling machine. (*Courtesy Whitney Mfg. Co.*)

milling and face milling operations it is more adaptable than the machine with the horizontal spindle because of the fact that the cutter and the surface being machined are in plain view instead of over back of the work.

143. Parts of the Milling Machine.—On the following pages are illustrated and described examples of the column and knee type of milling machine, manufactured respectively by the

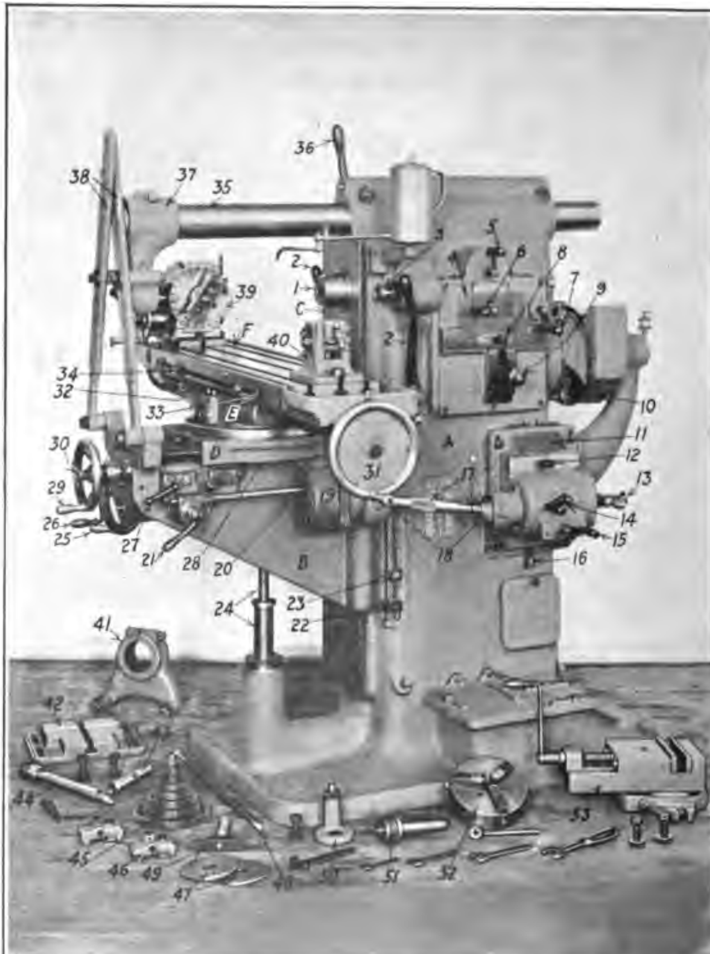


FIG. 140.

NAMES OF PARTS OF THE BROWN & SHARPE UNIVERSAL MILLING MACHINE

A. *Frame*, column and base cast in one piece, base pan-shaped to keep oil and chips off floor.
B. *Knee*, supports the saddle, saddle plate and table, adjustable vertically.
C. *Knee slide*, extends to top of frame to permit of attachments being clamped directly to face of column.
D. *Saddle*, has transverse movement on knee.
E. *Saddle plate*, may be swiveled 53° either side of zero; graduated in degrees; carries work table.
F. *Work table*.

SPINDLE DRIVE, LEVERS, ETC.

1. *Main spindle*, has front end tapered outside to centralize face mills, etc., and has No. 10 or larger B. & S. taper hole. End of spindle is recessed (slotted) to receive the cutter or arbor drivers.
2. *Friction Clutch Levers*, either may be used for starting or stopping machine without the necessity of stopping the motor.
3. *Spindle adjusting knob*, for obtaining a small part of a revolution of the spindle by hand with small wrench.
4. *Spindle speed index plate.*
5. *Quill gear lever*, moves sliding quill gears for obtaining fast or slow series of speeds.
6. *Spindle reversing lever* reverses direction of rotation of spindle.
7. *Back gear adjusting lever.*
8. *Spindle speed change intermediate gear stop*, for moving and locking intermediate gear in position to engage any one of the cone of gears.
9. *Spindle speed change intermediate gear lever*, moves intermediate gear in and out of mesh with any one of the cone of gears.
10. *Main driving pulley.*

FEED LEVERS, HAND WHEELS, ETC.

11. *Feed index plate.*
12. *Feed change intermediate gear stop* for moving and locking intermediate gear in position to engage any one of the cone of gears.
13. *Feed change intermediate gear lever*, moves intermediate gear in or out of mesh with any one of the cone of gears.
14. *Lever for moving feed change gears* (*upper*) moves sliding quill gears to obtain fast or slow series of feeds.
15. *Lever for moving feed change gears* (*lower*) moves sliding quill gears to obtain an additional series of fast or slow feeds.
16. *Feed chain adjusting screw* for adjusting length of feed chain for wear.
17. *Telescopic feed shaft* with universal joints. (All automatic feeds are transmitted through this shaft.)
18. *Universal joints.*
19. *Feed reverse gear case.*
20. *Feed reverse lever*, reverses all automatic feeds.
21. *Vertical feed trip lever*, controls automatic vertical movement of knee.
22. *Vertical feed safety dog* for preventing knee from running too far down.
23. *Vertical feed trip dog*, adjustable, throws feed out of action at any desired point.
24. *Knee elevating screw* (telescopic). Movrd by hand wheel (25).
25. *Hand wheel for vertical feed*, for use when adjusting or feeding table vertically by hand. First loosen knee clamping lever (26).
26. *Knee clamping lever*, for clamping knee to face of column after adjustment.
27. *Cross feed trip lever*, controls automatic transverse movement of table.
28. *Cross feed trip dog* adjustable, throws feed out of action at any desired point.
29. *Hand wheel for cross feed*, for transverse movement of saddle.
30. *Hand wheel clutch*, for disengaging hand wheel. Similar clutch on hand wheel for vertical feed (25).
31. *Table hand wheel*, for rapid longitudinal movement of table.
32. *Table feed trip lever* controls longitudinal movement of table, also reverses same Attached to this lever is adjustable stop which allows table to be fed only in desired. direction.
33. *Table feed safety dog* prevents table running too far.
34. *Table feed trip dog*, adjustable, throws feed out of action at any desired point.
35. *Over arm.*
36. *Lever for clamping over arm*, operates both front and rear clamps.
37. *Outer arbor bearing support.*
38. *Arm braces.*

ACCESSORIES

39. *Index head or spiral head* for use in indexing, the milling of spirals, etc.
40. *Foot stock* for supporting outer end of work when using index head.
41. *Arm support bracket.*
42. *Raising block.*
43. *Collet.*
44. *Differential indexing center.*
45. *Change gears*, used with the index head to obtain different leads in spiral milling and also to give various ratios in differentia indexing.
46. *Table stops*, for preventing longitudinal table movement.
47. *Index plates.*
48. *Draw-in bolt.*
49. *Face mill driver.*
50. *Center rest*, to support work carried by index head or on centers.
51. *Chuck collet*, to hold chuck (52) when used on main spindle.
52. *Chuck*, may be used either on main spindle or index head spindle.
53. *Swivel vise* for holding work.

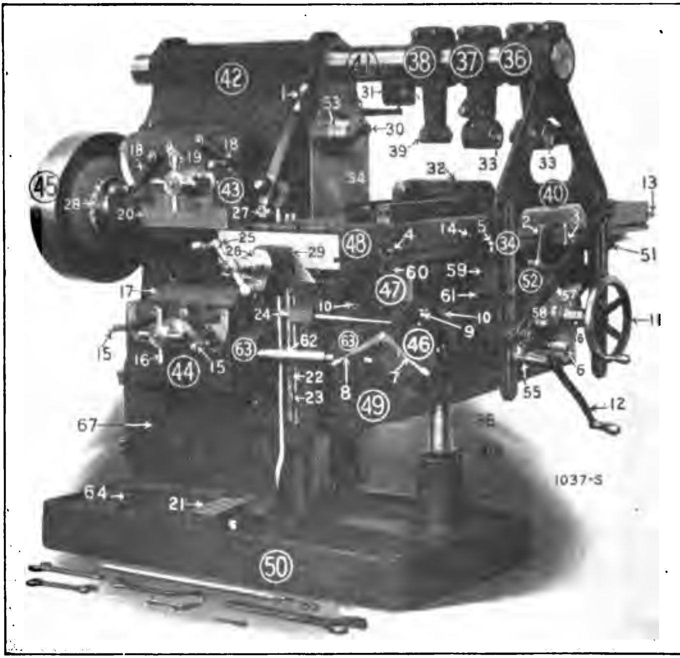


FIG. 141.—Cincinnati plain milling machine.

NAMES OF PARTS OF CINCINNATI MILLING MACHINES

Numbers in circles are on the part to which they refer, or they are directly over that part when it is concealed.

1. *Clutch lever* for starting and stopping machine.
2. *Table feed setting lever.*
3. *Power quick-traverse operating lever.*
4. *Table feed adjustable trip dogs.*
5. *Table feed trip plunger.*
6. *Cross* and *vertical feed setting lever.*
7. *Vertical* and *cross feed lever.*
8. *Lever* for operating feed when standing behind the table.
9. *Cross feed trip plunger.*
10. *Cross feed adjustable trip dogs.*
11. *Cross adjustment handwheel.*
12. *Vertical adjustment crank.*
13–14. *Quick-traverse limit stops.*
15. *Feed change levers.*
16. *Pilot wheel* for operating feed change tumbler.
17. *Feed index plate.*
18. *Speed change levers.*
19. *Pilot wheel* for operating speed change tumbler.
20. *Speed index plate.*
21. The *treadle* for giving the gears slight motion to facilitate speed changing.
22. *Guide* for vertical feed trip dogs
23. *Vertical feed, adjustable trip dogs.*
24. *Vertical feed trip plunger.*
25. *Ball crank* for longitudinal table adjustment.
26. *Micrometer dial* for longitudinal table adjustment.
27. *Rack* on main clutch rod.
28. *Quick traverse driving belt.*
29. *Bracket* containing left-hand bearing for table feed screw.
30. *Driving keys* in flanged spindle end.
31. *Oil pot.*
32. *All-steel vise.*
33. *Bushings* in arbor bearings.
34. *Table feed operating lever* (concealed behind the braces in Fig. 141, see Fig. 142).
35. *Telescopic elevating* (vertical feed) *screw sleeve.* The vertical screw (35-*A*) Figs. 142 and 143) is inside of this sleeve.
35-*A*. *Vertical feed screw* (Fig. 142).

Browne & Sharpe Manufacturing Co., and the Cincinnati Milling Machine Co. It is believed, since these machines embody all of the basic principles of milling machines of this class that a study of their construction and operation will prove helpful in understanding any make of similar machine.

144. The Milling Machine Drive.—While it is true that the use of high-speed steel cutting tools and the consequent heavy duty required of all classes of machine tools has made imperative many changes in design and construction which must be regarded as now necessary to obtain the best results and while it is acknowledged that the gear drive or "constant speed drive" is one of the most important of these improvements, yet it is also true that for many kinds of work even where unusual power is required the cone-pulley drive is still much used. This is because it is simpler and much less expensive.

The hand milling machines are cone-driven and are not provided with back gears. The smaller plain milling machines are cone-driven and are usually provided with back gears to give an additional series of speeds. The heavy-duty plain milling machines and usually the universal milling machines are regarded as more efficient when equipped with the constant speed drive.

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36. *Outer arbor bearing support* which can be bolted to the braces.
37. *Intermediate arbor bearing support.*
38. *Outer support,* for short arbors having a bearing on the outside of the nut.
39. *Adjustable bronze bush* for arbor bearing.
40. *Braces* for tying the overarm, outer arbor support and knee together.
41. *Overarm.*
42. *Column* of the machine.
43. *Drive box.*
44. *Feed box.*
45. *Driving pulley.*
46. *Feed reverse box.*
47. *Saddle.*
48. *Table.*
49. *Knee.*
50. *Base.*
51. *Bracket* containing right-hand bearing for table feed screw.
52. *Bridle* by which the braces are fastened to the knee.
53. *Front spindle bearing box.*
54. *Front face of column* where the construction number and letter will be found. Always give this number and letter when ordering attachments or repairs It identifies the machine.
55. *Micrometer dial* for vertical adjustment.
56. *Micrometer dial* for cross adjustment.
57. *Front sliding covers* in top of knee. *Back sliding covers* corresponding with these can not be seen.
58. *Cross screw bracket* at front of knee.
59. *Trip plunger bracket.*
60. *Adjustable gib* for table bearings.
61. *Adjustable gib* for saddle bearings.
62. *Telescopic universal joint shaft* (long fork).
63. *Universal joints* (short forks and ball in fork). The short fork connecting with the shaft in reverse box has a flange which carries the shearing pins (safety fork).
64. *Oil pump connection* with tank which is in the base of the machine.
65. *Ejector rod.*
66. *Vertical feed nut* on base of machine.
67. *Location of oil pump* when furnishe

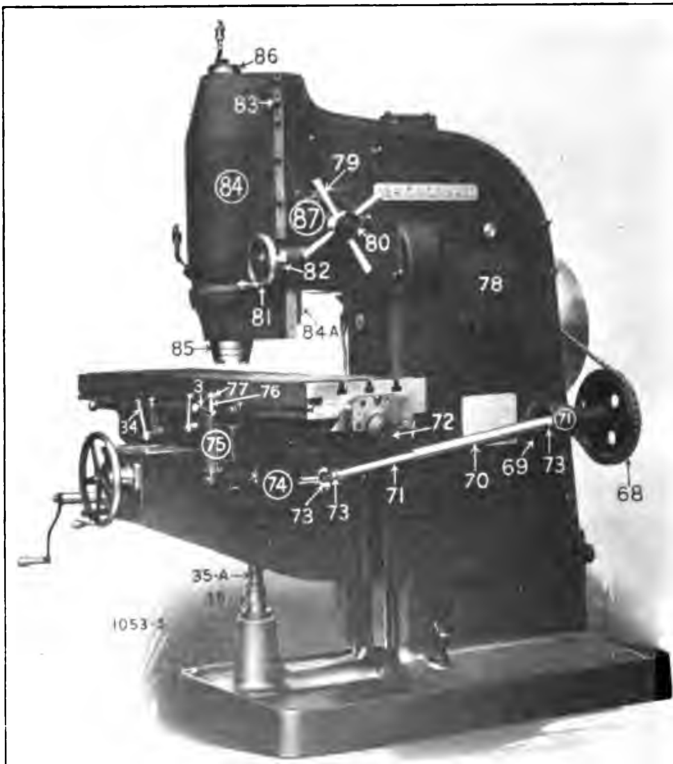


FIG. 142.--Cincinnati vertical spindle milling machine.

The following parts are shown in Fig. 142.

68. *Power quick-traverse pulley.*

69. *Quick-traverse bracket* on column.

70. *Long fork* on quick traverse shaft.

71. *Extension shaft,* quick traverse.

72. *Cover* over end of lead screw. (Remove when setting up for cutting spirals.)

73. *Short forks* of Universal joints. (These are identical with the forks used for driving the feed.)

74. *Quick-traverse bracket* under saddle.

75. *Quick-traverse operating lever bracket.*

76. *Quick-traverse lever shaft.*

77. *Quick-traverse safety lever.*

78. *Cover* over driving gears. (Remove when oiling inside parts.)

Additional Parts Applying to Vertica Machines Fig. 142.

79. *Pilot wheel* for quick adjustment of spindle (6″ per turn).

80. *Knob* for engaging hand feed movement.

81. *Handwheel* for hand feed movement.

82. *Micrometer dial* for hand feed movement.

83. One of four bolts for clamping spindle head solidly to frame of machine for heavy work.

84. *Spindle head.*

84-*A*. *Rack* for adjusting spindle head.

85. *Lower spindle bearing box.*

86. *Upper spindle bearing box.*

87. *Head adjustment worm casing.*

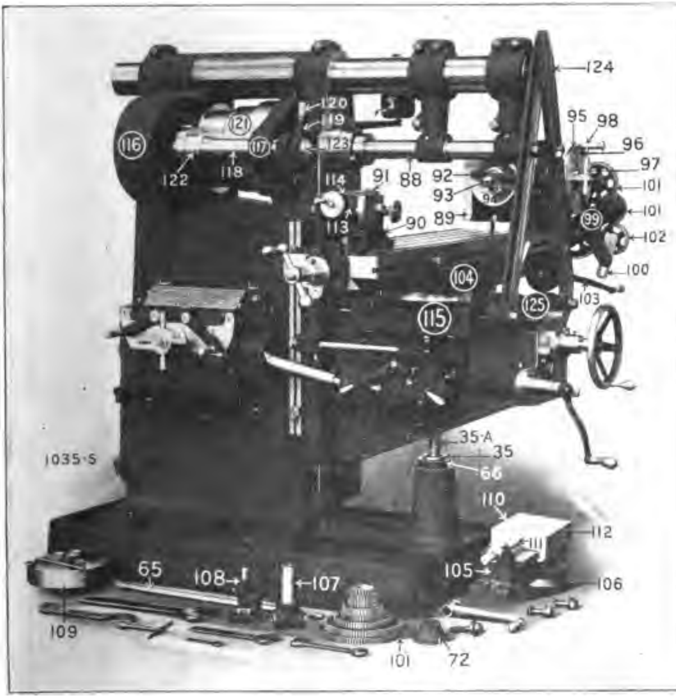


FIG. 143.—Cincinnati universal milling machine.

Additional Parts Applying to Universal Machine Fig. 143.

88. *Arbor.*
89. *Universal indexing* and *dividing head.*
90. *Tail stock.*
91. *Elevating center* for tailstock.
92. *Front index plate* on spindle for direct indexing low numbers.
93. *Head center.*
94. *Driver* for dog.
95. *Side index plate.* Drilled both sides, reversible.
96. *Sector* for convenience in indexing.
97. *Index pinholder.*
98. *Index pin* (in the holder).
99. *Segment* for change gears. (This segment with a complete set of change gears constitutes a driving mechanism.)
100. *Swinging arm* or *bracket* for idler gear.
101. *Change gears* for cutting spirals (12 in a set).
102. *Idler gear.*
103. *Quick-return crank handle.*
104. *Swivel carriage* or *housing.*
105. *Vise body.*
106. *Swivel base* for vise.
107. *Holder* for adjustable bronze bush for outer arbor support. (This is substituted for the large bearing holder in the intermediate arbor support).
108. *Steady rest.*
109. *Universal milling machine chuck.*
110. *Vise housing.*
111. *Vise screw.*
112. *Vise jaws.*
113. *Swivel block* in tail stock.
114. *Tailstock,* center carrier.
115. *Saddle* of universal machine.

Additional Parts Applying to Cone-driven machines.

116. *Cover* over back gears.
117. *Cover* over back gear pinion.
118. *Back gear quill.*
119. *Back gear operating lever.*
120. *Back gear locking pin.*
121. *Driving cone.*
122. *Back gear sleeve.*
123. *Back gear shaft.*
124. *Braces* as used on Nos. 1, 2 and 3 cone-driven machines.
125. *Bridle* for attaching braces to knee.

145. The Constant Speed Drive.—The general features of the constant speed drive are as follows: Power is delivered to a wide-faced pulley, which runs loose on a sleeve on the main driving shaft of the machine, through a belt from the countershaft or, in the direct drive, through a silent chain from a motor. By means of a friction clutch on the main driving shaft, operated by a convenient lever at the side of the column,

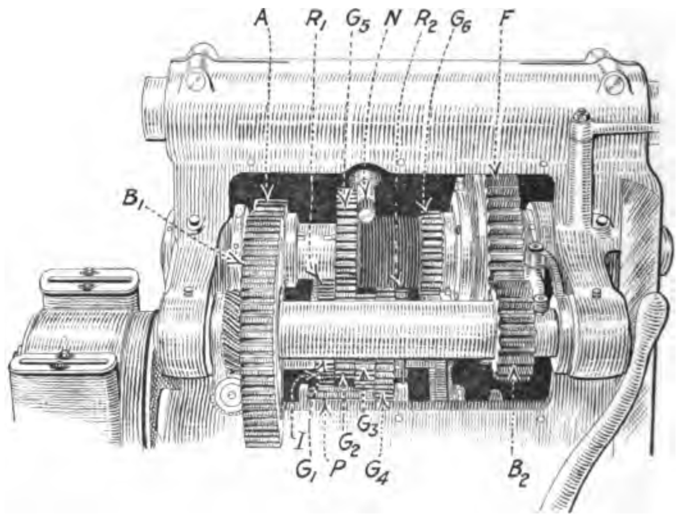


FIG. 144.—Brown & Sharpe milling machine spindle driving gears.

the motion is transmitted from the driving pulley to the driving shaft, and from this shaft through a train of hardened gears to the spindle.

In this train of gears there are certain quick change gears, operated by levers at the side of the column. The main driving pulley runs at a constant speed. When the clutch is in, the main driving shaft in the machine runs at the same constant speed. The various spindle speeds are entirely dependent upon the positions of the change gears and whether or not the back gears are engaged.

146. Description of the Spindle Drive, Brown & Sharpe Milling Machine.—The arrangement of the gearing in the head of the Brown & Sharpe milling machine is shown in Fig. 144 and for the purpose of developing the principles of this mechanism the diagram, (Fig. 146) may be used. Notations in the following description refer to either figure.

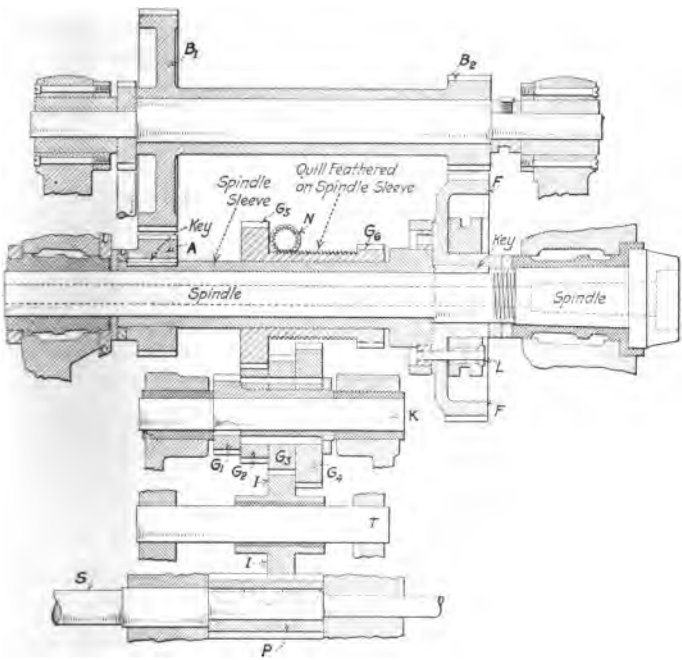


Fig. 145.—Diagram of spindle driving gears B. & S. milling machine.

When the friction clutch is operated to start the machine, power is transmitted to the main driving shaft *S* on which is mounted a sturdy long pinion *P*. Meshing with *P* is the intermediate gear (or tumbler gear) *I*. By moving a lever (8, Fig. 140) gear *I* will slide on its shaft *T* to any one of four positions and when in the proper position it may be raised by another lever (9, Fig. 141) to mesh with each one respectively of the cone of gears G_1–G_2–G_3–G_4 (for detail see Fig. 146).

These gears are fastened together and therefore the cone has four separate speeds to a constant speed of the driving shaft S. Mounted on a quill are two gears G_5 and G_6. When G_5 is engaged with G_2 as shown in the figure, anyone of four speeds of the quill are available. by turning the pinion N (lever (5), Fig. 141) which meshes in a series of grooves which form a rack on the quill, the gear G_5 is moved away from G_2, and G_6 engages G_4. With this combination four more speeds of the quill are obtainable. There are therefore eight speeds of the quill available by this change gear mechanism.

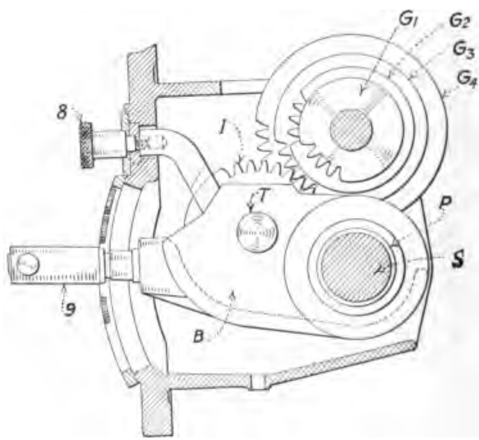


FIG. 146.—Section through tumbler gear unit, Brown & Sharpe milling machine. P is the driving pinion (see Fig. 145). The swinging frame B carrying the intermediate gear I (tumbler gear) is moved up or down by the handle (9). The handle (8) serves to move the frame B to bring the gear I under any one of the gears G_1, G_2, G_3 or G_4 as desired and also serves to lock the frame in position.

These speeds may be delivered directly to the spindle giving eight "direct" spindle speeds (faster series), or "indirectly" through the back gears B_1 and B_2 to give a series of eight slower spindle speeds.

Direct Spindle Speeds.—Note that the quill Q is feathered on the spindle sleeve; the front end of this sleeve forms a fairly large flange which is provided with a series of holes any one of which will receive the lock pin L. The lock pin is carried as in

other machines, lathes for example, by the face gear *F which is keyed to the spindle.* The eight direct speeds (faster series) are obtained when the lock pin is "in" thus locking together the face gear *F* and the spindle sleeve.

Indirect Spindle Speeds.—When the back gears are put "in" the lock pin is withdrawn, and the eight slower spindle speeds are obtained from the revolutions of the gear *A*, which is keyed to the spindle sleeve, *through the back gears* B_1 and B_2 to the face gear *F* which is keyed to the spindle.

NOTE.—In the Brown & Sharpe machine the lock pin is automatic in its action.

The Spindle Reverse.—The reverse of the spindle is obtained by bringing an extra gear in the train between the cone of gears and the quill gears. That is, for the four slower quill gear speeds a reversing gear is brought into mesh between G_2 and G_5 and for the faster quill gear speeds a reversing gear is brought into mesh between G_4 and G_6. The two reverse gears R_1 and R_2 are shown in *b* (Fig. 147). The studs on which these gears revolve are arranged to slide, one forward and the other back or *vice versa* by right- and left-hand screws. These screws are operated, both at the same time, by a gear controlled by the handle (6), *a*, (Fig. 147). Ordinarily both reverse gears are in neutral position. If, however, it is required to reverse the spindle, the quill is arranged in a neutral position, that is, it is slid half way, just far enough so that neither quill gear is in mesh with a gear on the cone. Then either of the reverse gears may be pushed forward and, having sufficient width of face, engages both the gear on the cone and the quill gear.

If the foregoing descriptions seem difficult to understand, study the directions given under Fig. 147 and then read the descriptions again.

147. Spindle Drive.—Cincinnati Milling Machine.—Figure 148 shows arrangement and Fig. 149 shows the development of the Cincinnati milling machine geared head which is an example of the use of a combination of the principles of the

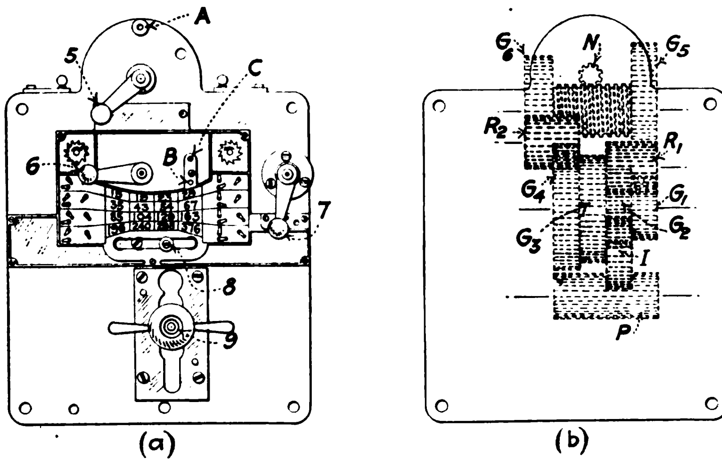


FIG. 147.—In the figure (*a*) shows the outside of the spindle speed case with the levers, etc., (*b*) illustrates a phantom view of the gears inside. Certain of these gears are shown in Figs. 244, 245 and 246 and notations are the same for the respective gears. View from right-hand side of machine.

Example.—To set the spindle speed for 54 r.p.m., first for left-hand cutter, *normal rotation* of spindle, then for right-hand cutter with reverse gear in.

Spindle reversing lever 6 in normal position as shown in *a*, (Fig. 147).

Quill gear lever (5) to the left (faster series of quill gear speeds, that is G_6 in Fig. 145 meshing with G_4).

Back gear lever (7) to left (back gears "in").

Intermediate gear stop (8) in position under 54 on index plate (intermediate gear I, Fig. 145 under G_2).

Intermediate gear lever (9) raised as far as it will go (raises gear I to engage G_2) and speed is set for 54 r.p.m.

Now to reverse rotation of spindle (same speed) move lever (5) to vertical position (locked in hole A). This slides the quill half way and arranges the quill gears neutral, as shown in b, that is, neither one is in mesh with gear on cone. Then move lever (6) down and around to hole B. This will move the reverse gear R_2 forward into mesh with G_4 and G_6.

NOTE.—If instead of moving lever (6) down and around to hole B it had been moved up and around to hole C the reverse gear R_1 would have been moved forward into mesh with G_2 and G_5. This would result in giving a spindle speed of 23 r.p.m.

tumbling gear, sliding gears, and positive clutch. The back gears B_1 and B_2 are enclosed within the head under the spindle; the main driving shaft M is not under, but more nearly in back of the cone gears as shown in the cross-section of tumbler gear unit Fig. 150.

The development (Fig. 149) shows the gears *arranged for the slowest spindle speed.* The motion is transmitted as follows: From the single drive pulley through a powerful

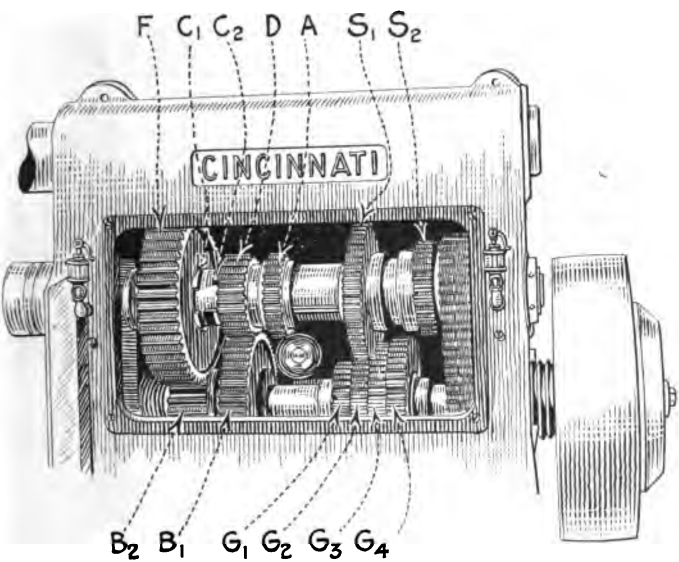


FIG. 148.—Cincinnati milling machine spindle driving gears.

friction clutch to the main driving shaft M to the driving pinion P. From P through the intermediate tumbling gear I to the larger gear G_4 on the cone, and from another cone gear G_2 to the larger gear S_1 on the sliding gear sleeve, through the spindle sleeve to gear D on the driving gear sleeve. (The *sliding gear sleeve* and the *driving gear sleeve* are both feathered on the long *spindle sleeve* which revolves freely on the spindle.) From D the motion is transmitted through the back gears B_1 and B_2 to the large face gear F which is keyed to the spindle,

While G_2 is meshing with S_1 as shown, one series of four speeds is obtained by meshing the intermediate tumbling gear I with each one respectively of the four gears of the cone of gears G_1, G_2, G_3, G_4 (for details see Fig. 150). The second series of four speeds is obtained when the sliding-gear sleeve

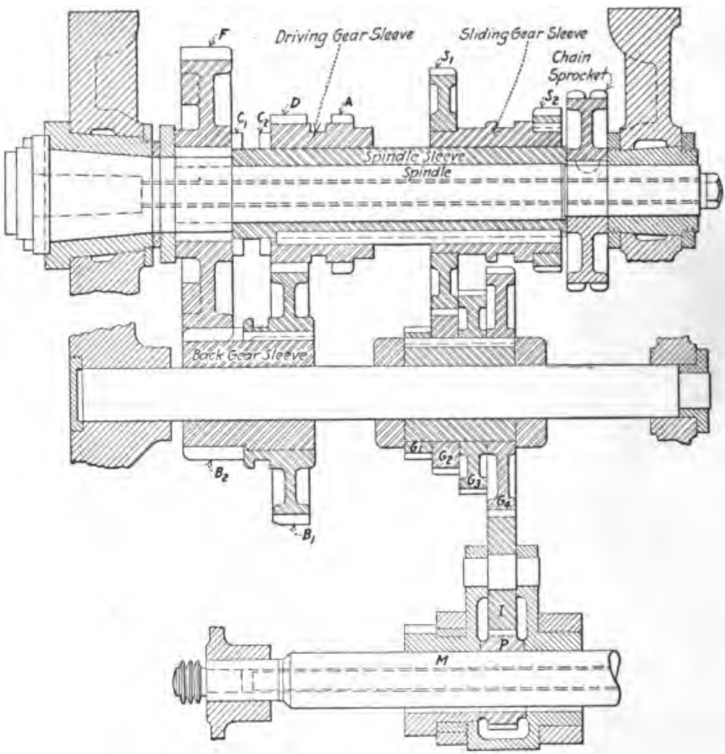


FIG. 149.—Diagram of driving gears Cincinnati milling machine.

is moved (*C-D* lever Fig. 151) to the left to bring S_1 out of mesh with G_2 and S_2 into mesh with G_4 and changing the tumbler gear I as above, that is, to G_1, G_2, G_3, or G_4.

By a movement of the *A-B* lever (Fig. 151) the back gear sleeve is moved to bring B_2 out of mesh with F and at the same time bring the positive clutch member C_2 on the driving

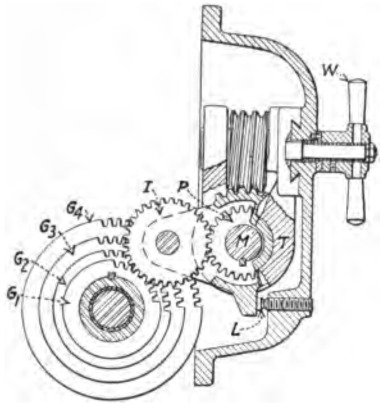


FIG. 150.—Section through tumbler gear unit, Cincinnati milling machine. *M* is the main driving shaft, see Fig. 149. The swinging frame carrying the tumbler gear *I* moves up or down on the trunnions *T* and is operated by the pilot wheel *W* through the worm and worm wheel. The pilot wheel serves also as a handle to move the tumbler frame laterally to bring the gear *I* over G1, G2, G3, G4, as desired and then a part of a turn of the wheel to the right engages the gears. For each of the four positions of the tumbler gear, the lug *L* on the frame abuts against a suitable stop pin to insure proper meshing of the gears.

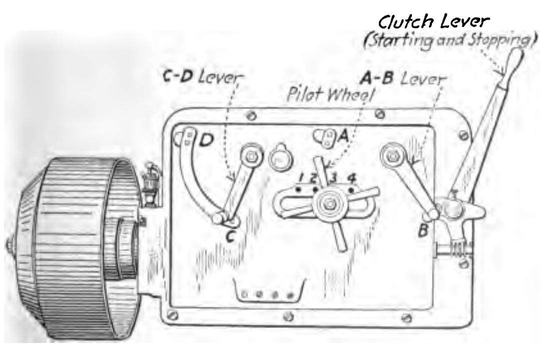


FIG. 151.—Speed change box.

A-B Lever operates the driving gear sleeve and the back gear sleeve, to *A* for back gear speeds to *B* for direct speeds.

C-D Lever operates the sliding gear sleeve, to *C* for the slower series to *D* for the faster series.

1–2–3–4 Pilot Wheel operates the tumbler gear for any one of four speeds.

gear sleeve into engagement with the other clutch member C_1 on the face gear F. Through this positive clutch two series of four speeds each as explained above may be obtained directly, that is, without the use of the back gears.

There are 16 changes of speed thus provided, two series of four each through the sliding gears and back gears and two series of four each through the sliding gears and the positive clutch.

NOTE.—The gear A acts merely as a pilot gear when throwing the back gears into engagement.

Questions on the Spindle Drive

1. What is meant by a cone of gears? What is an intermediate gear?

2. A tumbler gear is a gear so arranged on a bracket or a lever that it may be placed and locked in two or more positions. What gear in Fig. 145 is a tumbler gear? In Fig. 149.

3. From a constant speed of pinion P how many speeds may be transmitted to the spindle sleeve in Fig. 145? In Fig. 149?

4. The tumbler gear principle of speed changes is much used in machine construction. What different machines, in which this mechanism is used, can you find in the shop?

5. Explain the principle of the tumbler gear as applied to quick change of speeds.

6. What is a "sleeve" or "quill" in machine construction? What is a "feathered" sleeve? What is the purpose of the feathered driving gear sleeve in Fig. 149?

7. Why is one gear on the sliding gears sleeve in Fig. 149 larger than the other? From a constant speed of the driving pinion P how many speeds may be given to the sleeve?

8. When the feathered sleeve revolves why does the spindle sleeve revolve?

9. How is this motion transmitted directly to the spindle? How many direct speeds has the spindle? Why?

10. Why is the initial driving gear A (Fig. 145) of the back gear train keyed to the spindle sleeve and *not* to the spindle?

11. Explain why the fastest speed with the back gears in is slower than the slowest speed with the back gears out.

12. When does the main spindle revolve in the spindle sleeve?

13. The gears on the sliding sleeve in Fig. 149 are often called sliding gears or slip gears and this method of obtaining quick change of speeds

is much used in machine construction. Are you able to find any other machines in the shop where this mechanism is used?

14. What "machine" do most of us see every day in which this mechanical principle is used?

FEEDING MECHANISMS

In connection with the study of the feeding mechanism the diagram (Fig. 152) should prove interesting and helpful.

148. Initial Drive for Feeds.—The feed-box *driving shaft* is operated by a silent chain either from the main spindle as

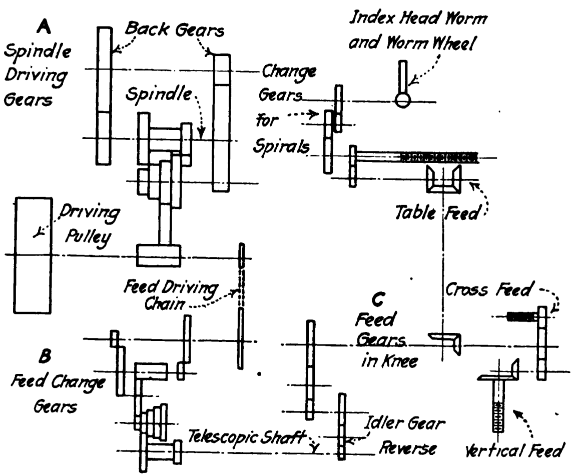


Fig. 152.—Diagram of gears in universal milling machine. (*Brown & Sharpe.*)

Spindle driving gears (group *A*) are same as illustrated in Fig. 145. Note similarity of design of feed change gears (diagramed *downward* towards telescopic shaft) and spindle driving gears (diagramed *upward* to spindle).

in the cone-driven machine or from the main driving shaft as (usually) in the machine with constant speed drive. In the first case the amount of feed depends upon the speed of the spindle and even with a considerable number of feed changes it is often impossible to get a feed fast enough (coarse enough) for the large slowly revolving cutter, or on the other hand, impossible to obtain a feed slow enough (fine enough)

for a small end mill, which to cut efficiently should operate at high speed and comparatively fine feed.

In the second case (as shown Fig. 152) where the feeding mechanism is operated directly from the main *driving shaft* the feed changes are entirely independent of the spindle speeds and any combination of speed and feed is available. This is another advantage of the constant speed drive and is particularly useful in heavy duty milling where slow speed is being used and a coarse feed is wanted.

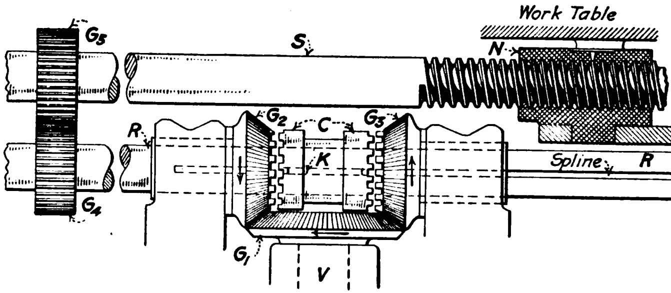


FIG. 153*A*.—Illustrates principle of bevel gear reversing mechanism as applied to milling machine table feed. (*Brown & Sharpe.*)

149. Feed Change Gear Box.—Modern milling machines having either cone-drive or constant speed drive are equipped with geared feed change mechanism. This *feed* change mechanism is very similar, in a given machine, to the *speed* change mechanism employed, two examples of which have been described. (Note similarity of spindle driving gears and feed change gears in Fig. 152.)

From the final driven shaft within the feed change unit or "feed box," motion is transmitted to the driving shaft in the reverse box, through a telescopic shaft with universal joints. This construction of the shaft permits of the knee being in any vertical position.

The various feeds are operated by feed screws and conveniently arranged hand wheels are provided for hand feed. The automatic feeds are obtained by means of suitable spur and bevel gears arranged to move the feed screws when connected

through positive clutches, and these clutches are engaged or disengaged by levers within easy reach of the operator. In addition, adjustable dogs may be set to trip the feed levers for the purpose of automatically stopping the feed at any desired point.

150. Reverse Box.—Through the driven shaft in the reverse-box (19), (Fig. 141) and (46), (Fig. 142) motion may be trans mitted to any feed screw and of course reversing the direction of rotation of this shaft reverses the direction of the feeds.

The reversing mechanism may comprise the bevel gear reverse principle (see par. 151) or the extra spur gear principle.

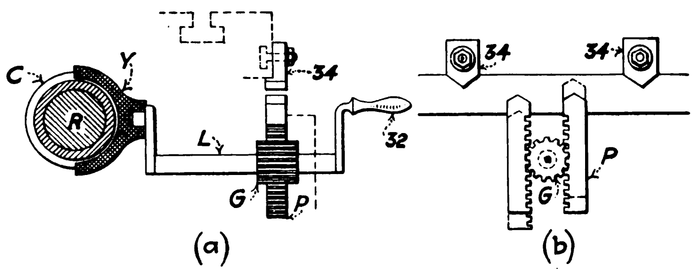


FIG. 153*B*.—Shows principle of operation of sliding clutch member *C* in Fig. 153*A*. The Yoke *Y* fits freely in the groove in the clutch and is operated by the lever 32 (see also No. 32 Fig. 140). Fastened to the lever shaft *L* is the gear *G* that lies between two plungers *P* which are provided with rack teeth as shown in *b*. When lever is in a vertical position the clutch *C* is neutral. When *C* is moved to engage either bevel gear (Fig. 153*A*) one plunger is raised and the other is depressed as shown by dotted lines (*b*, Fig. 153*B*). As the table feeds and the dog 34 comes against and pushes down the plunger *P*, it turns the gear *G* which serves to move the lever *L* and the yoke *Y* and thus disengage the clutch.

151. The Table Feed and Bevel Gear Reverse.—The principle of the gearing for the table feed (longitudinal) is shown in part in Fig. 153*A*. For the convenience of the operator the manufacturer of milling machines provides a *table feed reversing mechanism* in addition to the reverse gears for all feeds in the reverse box. The splined feed rod *R* and the feed screw *S* are connected at the left by spur gears. The sliding clutch member *C* is feathered as at *K* on the feed rod *R* and engages clutch teeth milled in the hubs of the bevel gears G_2 and G_3 when

moved to the *left* or *right* respectively, and engages neither when in a neutral (middle) position. The gears G_2 and G_3 are both free to turn in their respective bearings and are caused to revolve by being engaged with a larger bevel gear G_1 which is mounted on a vertical shaft below. It is obvious that the gears G_2 and G_3 revolve in opposite directions, and that the direction of rotation of the feed rod R and consequently of the feed screw S (that is, R. H. or L. H. table feed) is dependent upon the position of the clutch member C.

NOTE.—This principle of bevel gear reversing mechanism is much used in machine construction.

The way in which the clutch member C is moved either by hand or automatically is illustrated in Fig. 153*B*.

For each of the other feeds (cross feed and vertical feed) a single positive clutch is provided together with the yoke and lever for engaging or disengaging the clutch with the gear that drives it.

152. Attachments for Milling Machines.—By means of various attachments, which have come to be recognized as practically standard equipment for the column and knee type of milling machine, many jobs can be done more quickly and conveniently than otherwise, and, in addition, a large variety of operations may be performed on one machine that without the attachments would require several kinds of machines.

The manufacturers of milling machines furnish attachments that are interchangeable on their own make of machines of the same size, and many of these attachments, especially those which are clamped to the table, may be used on different sizes of machines or even on different makes of machines.

The index centers (Fig. 154) consisting of the index head and tailstock, comprise the most important attachment for the milling machine. The mechanism of the head is described beginning page 244.

The raising block (Fig. 155) is used when it is required to locate the dividing head at any other than its regular position on the table. It is provided with T-slots for the dividing head bolts. In addition the T-slots are accurately milled to

fit dividing head keys and are parallel to a finished edge of the block.

The tilting table (Fig. 156) is very useful when milling tapers. The vise, the index centers, or the work may be clamped on this table.

Fig. 154.—Index centers.

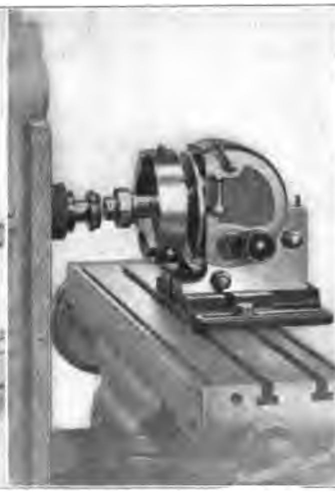


Fig. 155.—Raising block.

The Vertical Spindle Milling Attachment (Fig. 157).—The spindle in this attachment can be set and securely clamped at any angle in a vertical plane, the position being indicated by

Fig. 156.—Tilting table.

graduations in degrees. This attachment offers an easy means of doing many kinds of jobs which would be very inconvenient to do with the cutter held in the main spindle, and, more im-

portant, makes it possible to produce work that would otherwise require a vertical spindle milling machine.

The Universal Milling Attachment (Fig. 158).—The spindle of this attachment may be set and securely clamped at any angle in either a vertical or horizontal plane, the positions being indicated on the swivel plates by graduations in degrees. Besides having the advantages of the regular vertical spindle attachment this attachment offers also the advantages to be

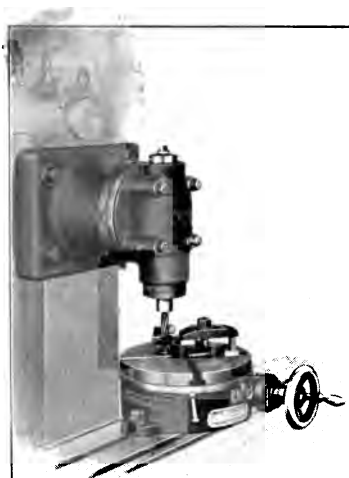


FIG. 157.—Vertical spindle milling attachment and circular milling attachment.

FIG. 158.—Universal milling attachment.

obtained by the use of a second swivel at right angles to the first, making it possible to take milling cuts at any angle in either plane.

The High-speed Milling Attachment (Fig. 159).—Small milling cutters are efficient only when operated at the proper cutting speed. This attachment offers a means of obtaining a speed from four to six times the regular spindle speeds, since motion is transmitted from a gear fastened to the machine spindle to a pinion about one-fourth to one-sixth as large on the attachment spindle.

The Slotting Attachment (Fig. 160).—The tool holding slide has a reciprocating motion and is driven by an adjustable crank which allows the length of the stroke to be changed. The head may be swiveled to 90° either side of center, the position being indicated by graduations in degrees. This attachment is very useful for cutting keyseats and for finishing the sides of square, oblong, or even irregularly shaped holes such as are frequently needed in medium sized machine or tool work. A set of cutting tools which consists of various

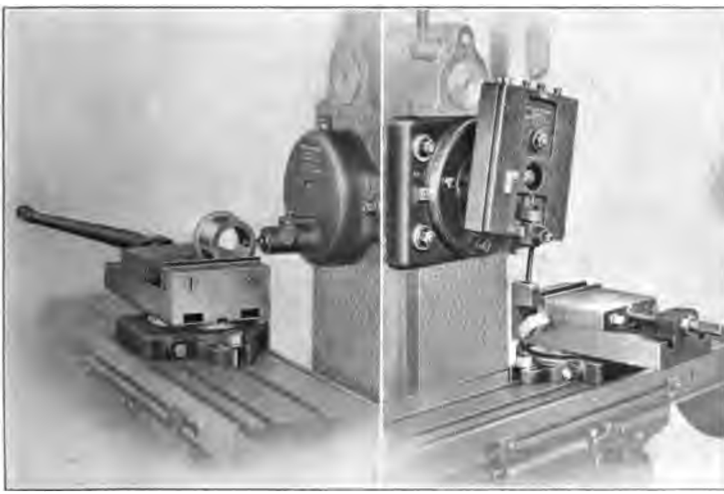


FIG. 159.—High speed attachment. FIG. 160.—Slotting attachment.

sizes of rounds, squares and special shapes is furnished with the attachment. These tools have cylindrical shanks and are secured in the holder by means of a set screw. It is a simple matter to make special tools of the shape or size required.

The Circular Milling Attachment (Fig. 157).—An especially valuable attachment for a vertical milling machine, or for a horizontal machine when used with a vertical spindle attachment or a slotting attachment. The circular table is rotated by means of an enclosed worm and wormwheel. The smaller

FIG. 161.—Rack milling attachment.

size is provided with hand feed only but the larger size is driven from the feed box and is provided with an automatic feed trip and adjustable feed trip dogs.

The Rack Milling Attachment (Fig. 161).—An almost indispensable attachment if racks more than 10 in. or 12 in. in length are to be cut. More special in its application, however, than most other attachments.

Questions on Milling Machine Construction

1. Clean and oil the table elevating screw and the finished surface of the column. Loosen the knee clamp and lower the table. What is the advantage of the "telescopic" elevating screw? How is it oiled?

2. How is the knee clamped to the column? What kind of a gib is used? How is the flat bearing surface oiled?

3. On certain machines a line on the knee sliding surface of the column marked "center," when split by the top surface of the knee indicates that the index head and tail centers are in same plane with center line of main spindle. Are you able to find this line? With three or four other fellows test your abilities in splitting the line.

4. Clean and oil the table bearing. How much longitudinal feed has the table? How is the table bearing gib adjusted?

5. Clean and oil the saddle bearings. How much cross feed has the table?

6. Why should the spindle hole be clean? Why should it be wiped dry?

7. What is the standard taper of the spindle hole? What number of taper is it?

8. How many spindle speeds has this machine? Why so many?

9. What is the normal direction of rotation of the spindle? Why? How is the reverse direction of the spindle obtained?

10. Set the feed mechanism for the slowest feed and throw in the table feed. How far does the table feed in 1 minute?

11. Is the feed in this milling machine independent of the spindle speed?

12. How do you reverse the table feed?

13. Arrange the feed mechanism for the fastest feed. How far does the table move in 1 minute?

14. Is there a power vertical feed? Is there a power cross feed?

15. How are all automatic feeds reversed? Which principle of reversing gears is used in this case?

16. If this milling machine has gear feed, are you able to explain the "gear case" mechanism?

17. Make a sketch which will show the principle of the bevel gear reversing mechanism.

18. Are you able to find in any machine in the shop a bevel gear reverse in which the clutch operates by friction instead of through clutch teeth (see Fig. 11). What, in your judgment, are the advantages of each?

19. Are you able to sketch a bevel gear reverse in which both the reversing gears are keyed to the shaft? (See Fig. 32, Part 1.)

20. What is the reason for having a telescopic feed shaft with universal joints?

21. Which is the most important attachment for the milling machine?

22. How is the raising block used? Are the T-slots accurately milled? Give reason.

23. What advantage has the vertical spindle milling machine? What is the value of the vertical spindle attachment?

CHAPTER IX

MILLING CUTTERS AND THEIR HOLDING DEVICES

154. Classification of Milling Operations.—There are fou distinctly different milling operations classified as follows

Plain milling or *slab milling*—the production of a flat surfac parallel to the axis of the cutter (Fig. 162).

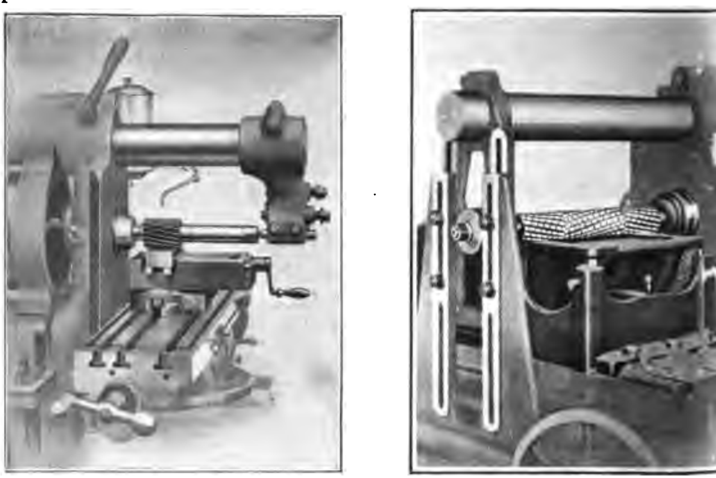


FIG. 162.—Illustrates two examples of plain milling.

Face milling—the production of a flat surface at right angle to the axis of the cutter (Fig. 163).

Angular milling—the production of a flat surface at a inclination to the axis of the cutter (Fig. 164).

Form milling—the production of a surface having an irregu lar outline (Fig. 165).

Certain particular operations have their obvious names such as "grooving," "slotting," "sawing" (Fig. 166), "gear cutting" etc. Milling flutes is a term applied to the groov ing of drills, reamers and taps (Fig. 167). When two or more

FIG. 163.—Face milling.

FIG. 164.—Angular milling.

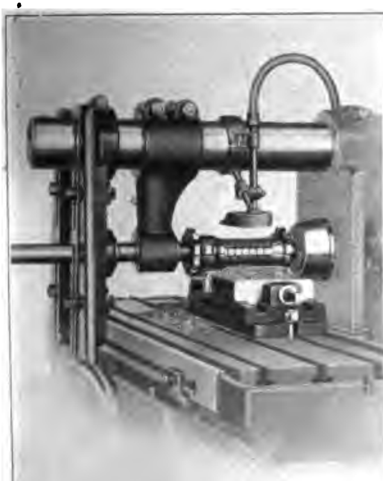


FIG. 165.—Form milling.

FIG. 166.—Sawing flat stock.

cutters are used together on one arbor the operation is called "gang milling" (Fig. 168 also Fig. 165). Face milling is sometimes called "side milling" and "straddle milling" is the term applied when two side milling cutters are used and two sides of a piece are milled at the same time. In Fig. 169 the two outside cutters are side milling cutters and the two flat bearing surfaces are being straddle milled. "Profiling" is milling to a predetermined outline by means of a guide bar and template. (A Profiling Machine is illustrated in Fig.

FIG. 167.—Milling flutes. FIG. 168.—Gang milling.

137.) "Routing" is milling to a more or less irregular outline while guiding by hand.

155. Milling Cutters, Introduction.—From the illustrations of the kinds of milling operations given, it will be apparent that a great variety of kinds and sizes of milling cutters are used. There are, in fact, over 50 different kinds of cutters on the market made in over 4,000 different stock sizes, one company alone making over 3,600 different sizes of stock cutters.

It is not enough to know that there are several kinds of cutters and a lot of sizes. The machinist should know the *names* of the cutters, and in a general way the *sizes* that may be obtained. He should know the *uses* of the cutters. The same cutter may be used for a variety of operations, and on the other hand any one of a number of kinds of cutters may be used to perform a given operation. In milling, as in other machine shop work, the resourcefulness of the machinist is often taxed to perform the given operation. For example, the

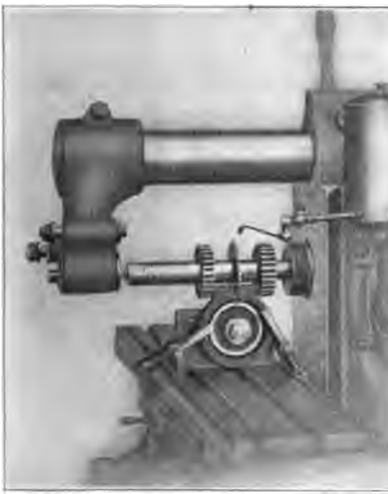


FIG. 169.—Straddle milling.

FIG. 169*A*.—Milling end teeth.

best cutter to use may not be available, but another kind of cutter may do almost as well, and the job finished without delay.

It is easy enough to become familiar with the names and sizes, but to get acquainted with *uses* of the various cutter will require more time and greater effort.

Learn to call for cutters by their name and the size required. Do not be satisfied to use a cutter the family name, given name and general characteristics of which you do not know. Get an idea of what the rest of the family, the big ones and the

little ones, are like. For example, in a watch factory is used a slitting cutter 1 in. diameter $\frac{1}{64}$ in. thick; in an armor plate mill is used a similar cutter, same family, 6 feet diameter and 2 in. thick. How many sizes of metal slitting cutters are you able to find in the tool room? How many sizes are given in a catalog of cutters?

Learn the uses of the cutters by study, reasoning, asking questions and observation. One young man who intelligently uses his "head," his tongue, his ears and his eyes is worth any number of mentally lazy fellows. Look around and size it up for yourself.

TYPES OF MILLING CUTTER TEETH

There are three distinct kinds of teeth used in the manufacture of milling cutters. *The Saw Tooth*, the *Formed Tooth* and the *Inserted Tooth*.

156. The Saw Tooth.—Until within a few years the saw tooth (Fig. 170) was almost universally used for all kinds and shapes of milling cutters. It is the cheapest type of tooth to produce either in a straight or spiral form and is still largely used in end mills, metal slitting cutters and in the smaller sizes of plain milling cutters. It will be observed that the cutting edge is given clearance by backing off the "land" about five degrees. This is done in the grinding machine when the cutter is sharpened (see p. 207).

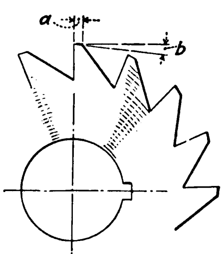


FIG. 170.—Shows clearance (b) on land (a) of saw tooth of milling cutter.

157. The Formed Tooth.—One of the chief values of the milling machine is the production of a large number of duplicate pieces having curved, shouldered or other irregular surfaces. This kind of work can be done very much quicker in the milling machine than in any other machine, such as the shaper or planer. Also a very large number of pieces may be milled without changing the setting of the machine, thus making it possible

to use more or less inexperienced workmen and still produce a fine and accurate grade of work. Owing to the fact that the plain milling cutter tooth of an irregular outline cannot be sharpened without changing the contour of the cutting edge, this tooth has been largely superseded, in the milling of irregular surfaces, by what is known as the formed tooth. For finishing certain irregular shapes to an exact outline, the use of the formed tooth cutter (Fig. 171) in

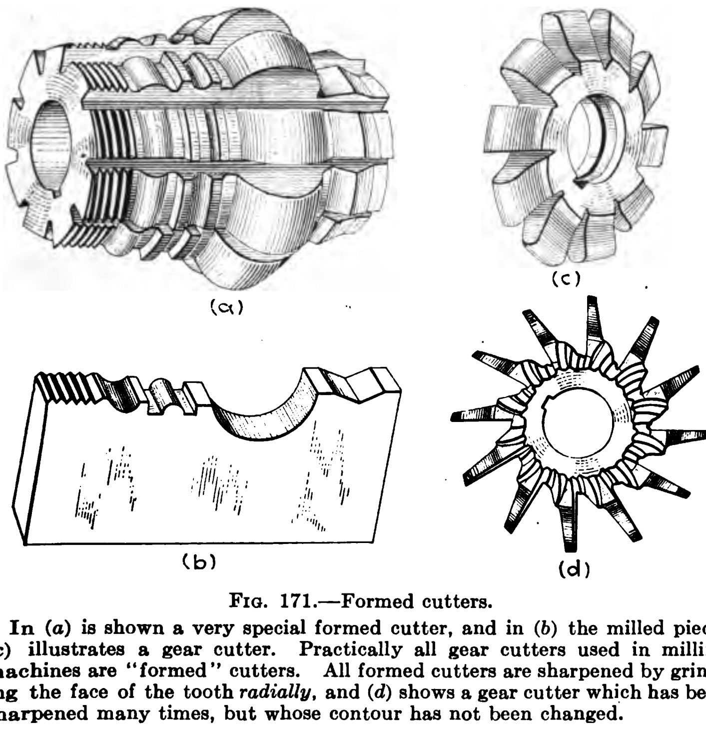


FIG. 171.—Formed cutters.

In (*a*) is shown a very special formed cutter, and in (*b*) the milled piece; (*c*) illustrates a gear cutter. Practically all gear cutters used in milling machines are "formed" cutters. All formed cutters are sharpened by grinding the face of the tooth *radially*, and (*d*) shows a gear cutter which has been sharpened many times, but whose contour has not been changed.

the milling machine is the most efficient method. A surface with an under cut cannot be finished in this way but for most other irregular surfaces of a size not too large, and a quantity production that will warrant the cost of the cutter, this kind of cutter is advantageous. The formed cutter may be used if

desired with other cutters to make up a gang (Fig. 165). The special advantage of the formed cutter lies in the fact that it may be sharpened many times without changing the shape of the cutting edge if, when sharpened, the *face of the tooth is ground radially.*

The formed cutter is made by leaving a land of considerable width between the grooves and then backing off or relieving this land eccentrically. This is accomplished in a special machine or in a lathe having a relieving attachment, by means of a forming tool of the correct shape, so held that its face is on a radial line with the cutter, that is "on center," and so arranged in the machine or attachment as to automatically feed in to back-off the land of each tooth and snap back through the tooth space ready for the next tooth, as the cutter slowly revolves (Fig. 172).

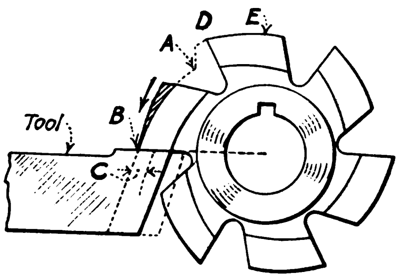


FIG. 172.—Backing off a formed cutter. Note the eccentric curve of the land of the tooth; the tooth has been "backed off" or "relieved" or "given clearance" an amount equal to the shaded portion above *B*. As the cutter revolves and the point *A* approaches the point *B*, the tool moves "in" and when point *A* has reached point *B* the tool has moved in an amount equal to *C*. Then the tool snaps back ready to start at *D* its motion "in" to back off the next tooth *E*. A slow speed and a very fine feed (cross feed) is necessary.

158. The inserted tooth cutter, (Fig. 173), has become very popular since the advent of high-speed steel. Cutter blades made of high-speed steel are inserted and rigidly held in a blank made of machine steel or cast iron. There are various methods of holding the blades employed by the different manufacturers. Inserted tooth cutters are especially efficient for the reasons that they are economical in the first cost and the wornout or broken blades can be replaced by new blades. It is an especially desirable way of making large cutters.

159. Kinds of Milling Cutters.

Plain Milling Cutter.—The most common form of milling

cutter is known as the plain milling cutter (Fig. 174), which is merely a cylinder having teeth cut upon its periphery for the purpose of producing a surface parallel to the axis of the cutter. When over ¾ in. wide the teeth are usually cut on a spiral. The object of the spiral tooth is to give a shearing cut. The shearing cut reduces the stress upon the tooth by preventing a distinct shock which occurs in a cutter with straight teeth when each tooth starts to take its chip. The spiral tooth cutter produces a better and smoother finish, requires less power to operate, and reduces the tendency to chatter. When of considerable length relative to the diameter these cutters are called "slabbing cutters." Slabbing cutters are frequently made with nicked teeth, the nicks following each other alternately.

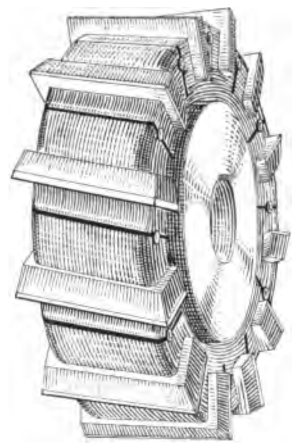
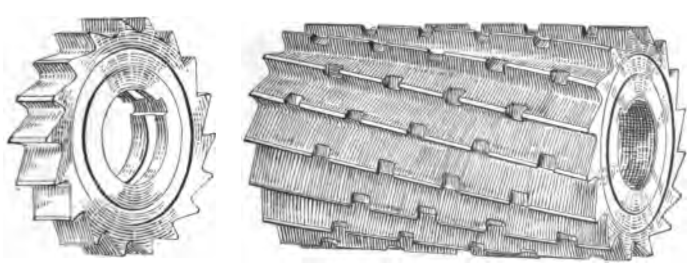


FIG. 173.—Inserted tooth cutter.



Plain Milling Cutter

Plain Milling Cutter with Spiral Nicked Teeth

FIG. 174.—Plain milling cutters.

The object of the nicks is to break up the chip and make it possible to take a coarser feed.

Metal Slitting Cutter (Fig. 175).—This is essentially a thin plain milling cutter the sides of which are finished true by grinding. These cutters are ground a little thinner towards the center, that is, they are given clearance toward the center in order that the sides of the cutter will not rub in the groove.

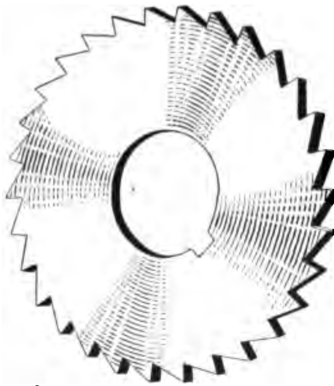
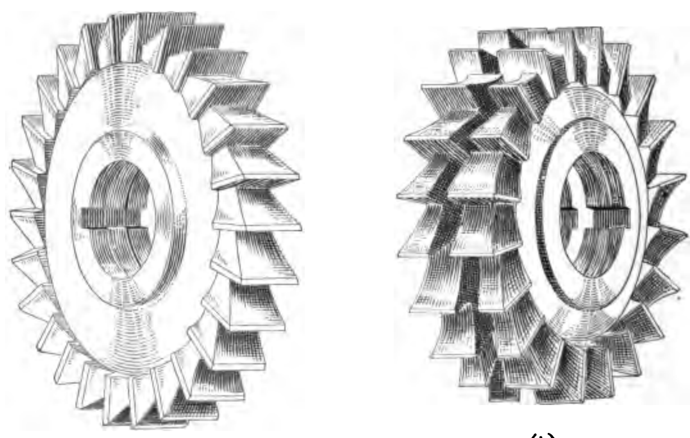


FIG. 175.—Metal slitting cutter or slotting cutter.

Side Milling Cutter.—Figure 176*a* shows a side milling cutter. This is a plain milling cutter with the addition of teeth on both sides. "Side mills" are frequently used in pairs with a collar between, and when so used are often called "*Straddle Mills.*" Pieces such as bolts, nuts, tongues, etc.,



(a)
Side Milling Cutter

(b)
Interlocking Side Milling Cutter

FIG. 176.—Note in (*b*) the thick and thin sections "interlocking."

that are to be milled on two parallel sides can be easily and accurately machined with a pair of side mills.

For milling slots to a standard width the interlocking side milling cutter (Fig. 176*b*) may be used. This cutter is made

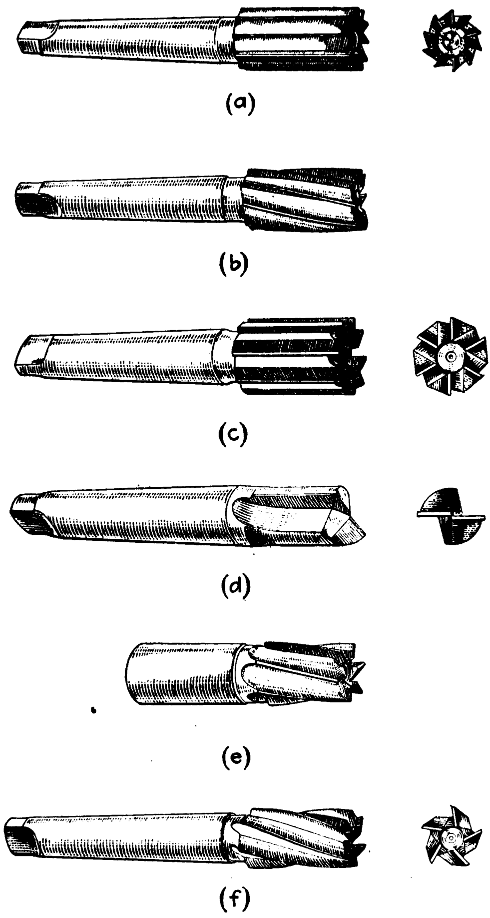


FIG. 177.—Types of end mills, (*a*) with straight teeth, (*b*) with spiral teeth; (*c*) with "center cut," the end teeth are backed off on the inner ends (recess); (*d*) two lipped slotting end mill; (*e*) straight shank end mill; (*f*) high speed type, has coarse teeth undercut to give rake and has also a steeper spiral than *b* or *e*.

in two parts, in fact there are two distinct cutters, with the inner surfaces of both parts milled to interlock. Even with

repeated sharpenings the correct width of the slot may be maintained by placing thin metal washers between the hubs. If the cutters were not "interlocking" a ridge as wide as the space between the cutters would be left in the work.

End Mills.—This kind of cutter has teeth on the periphery and at the end. Several different types of end mills are shown in Fig. 177. End mills may be used for a large variety of light milling operations such as machining the edges of fairly thin pieces, for squaring the ends of smaller pieces and often for making a corner cut (shoulder) where a fillet is desired. For slots or keyways it is often impossible to use any other form of cutter. End mills of a size over $\frac{5}{8}$ in. are usually made with spiral teeth on the periphery.

Cotter Mill.—In Fig. 177*d* is represented a two lipped slotting end mill sometimes called a cotter mill (from the English term "cotter" or key). It is used for cutting slots and keyways. These mills, having end teeth to the center similar to the lips of a drill, may be used for milling deep slots from the solid metal where there has been no drilled hole provided for starting the cut. The best results are obtained by a high surface speed with (1) a fairly deep cut and fine feed or (2) a fairly shallow depth of cut with a coarse feed. Use plenty of cutting lubricant.

End mills over 2 in. in diameter are made detachable from the shank as shown in Fig. 178. These are known as *shell end mills* and are designed for the purpose of economy in replacing the cutter without necessarily replacing the shank. Shell end mills have a standard sized hole of the proper diameter and have a slot milled diametrically across the back to fit a tongue on the arbor. The cutter may be held on the arbor by a cap screw (Brown & Sharpe style) or may be shrunk on (Cincinnati Milling Machine Co. style). To shrink on the cutter warm it in hot water, place it on the arbor tight against the shoulder and cool by slowly immersing in cold water *shank end first.*

Facing Cutter.—The larger sizes (diameters) of cutters having teeth on one end or face are not provided with shanks but

are fastened on the end of the machine spindle. They are called face milling cutters or face mills and are usually made with inserted teeth (see Fig. 194).

T-Slot Cutter (Fig. 179).—This form of cutter is used for finishing T-slots in work tables, etc. The central groove is

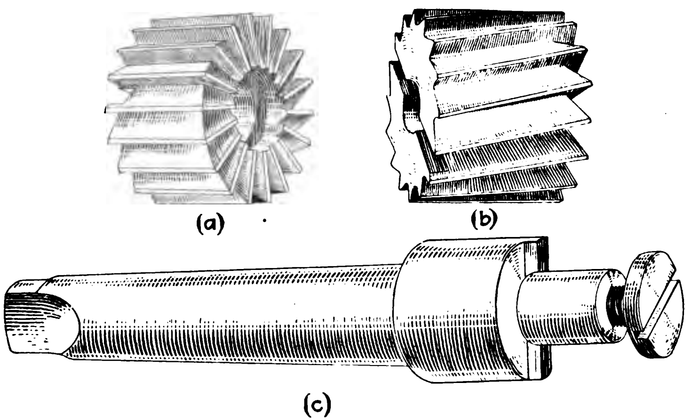


FIG. 178.—Shell end mills and arbor.

milled with a side mill or an end mill and then the wider part is milled with the T-slot cutter. T-slot cutters are made 1/32 in. over nominal diameter and 1/64 in. over nominal thickness to allow for sharpening. It will be observed that every other tooth is cut away alternately on each side. This makes for

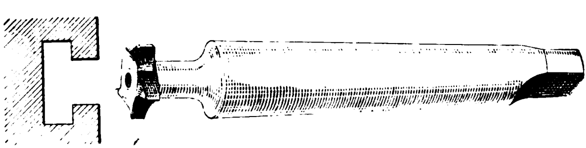


FIG. 179.—T-slot and T-slot cutter.

greater freedom of chip movement and greater ease in sharpening. The different cutter manufacturers make a variety of sizes, too great a variety in fact. Having only a few sizes, comparatively, of standard T-slots would surely save a lot of trouble.

Angular Cutters (Fig. 180).—The cutting teeth of an angular cutter are neither parallel nor perpendicular to the axis of the cutter but are at some oblique angle such as 60°, 70° or 80°. These cutters are used to cut teeth in ratchet wheels, for milling dovetails etc. Sometimes the straight side is provided with teeth to give a better finish with this side when cutting grooves.

FIG. 180.—Left-hand angular milling cutter.

Double Angle Cutters.—In Fig. 181 at *a* is shown a double angle cutter which is used for cutting spiral teeth in milling cutters, etc., and *b* illustrates how this cutter is set to obtain a radial tooth. These cutters are usually made with an angle of 12° on one side and 40°, 48° or 53° on the other. The illustration shows a formed tooth cutter which has a much longer life than the saw tooth cutter. Double angle cutters as shown, either right-hand or left-hand, also double angle cutters for milling symmetrical 90° *V*'s are made in many sizes with either saw teeth or formed teeth.

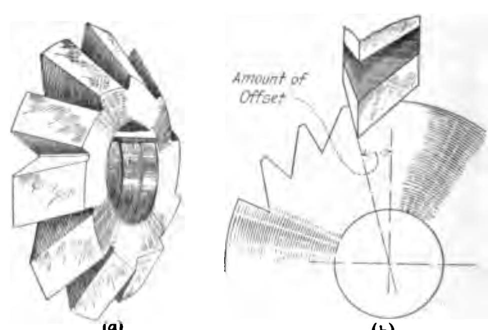


FIG. 181.—(*a*) Double angle cutter, left hand, for fluting cutters with saw-like teeth either straight or spiral. (*b*) Shows cutter off set to give radial face.

Tap and Reamer Cutter.—Figure 182 illustrates a cutter for grooving taps and reamers and *a* and *b* show the manner in which the cutter is set to give a radial tooth. This cutter is substantially a double angle formed tooth cutter with the

points of the teeth well rounded. Tap and reamer cutters are made in several sizes and each size is stamped with the range of the diameters of taps and reamers for which it may be used.

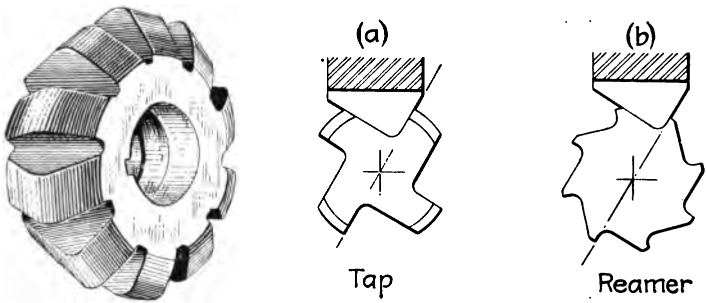


FIG. 182.—Tap and reamer cutter.

Corner Rounding Cutters.—Figure 183 shows left-hand, double and right-hand corner-rounding cutters which are used for the purpose of finishing the corners and edges of work. These cutters are made for any desired radius.

FIG. 183.—Corner rounding cutters.

Convex and Concave Milling Cutters.—Figure 184 shows convex and concave formed milling cutters used for milling half circles or parts of half circles.

Fly Cutter.—The simplest form of cutter is the fly cutter, several shapes of which are shown in Fig. 185 together with

the *fly cutter-holder* or *arbor*. It is a very useful form of cutter for experimental or hurry-up jobs where it would be impracticable on account of the time and expense necessary to make a regular formed cutter. It is simply a piece of square steel the end of which is formed (usually filed) to the desired shape backed off and hardened. The shank of the arbor fits the taper hole in the milling machine spindle and the tool should be tightly clamped in the arbor.

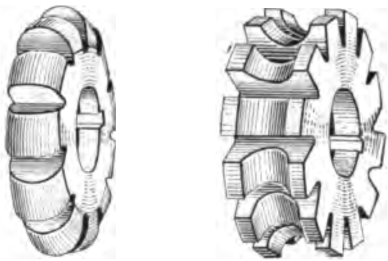


Fig. 184.

160. Right-hand and Left-hand Cutters (Fig. 186).—Milling cutters are said to cut right-hand or left-hand according to the direction in which the cutter revolves when observed from the *back* of the machine or the back of the cutter. Cutters may be mounted on an arbor to be used either way, but angular cutters are marked *R* or *L* assuming the angular teeth to be on the back side. Attention is called to the fact that a *left-hand* end mill is given a *right-hand* spiral, and vice versa, in order that the reaction against the tooth as it peels off the chip will tend to force the cutter towards the spindle rather than to loosen it. This is true also of spiral slabbing mills. It is customary, however, in heavy gang milling, as shown for example in Fig. 168, to use both right-hand and left-hand *spirals* to balance the force against the spindle thrust bearing.

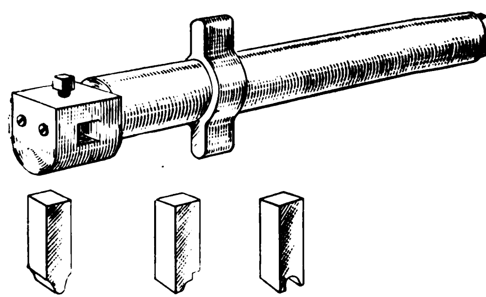


Fig. 185.—Fly cutter arbor and typical cutters.

161. Advantages of Coarse Teeth (Fig. 187).—The many practical experiments and tests that have been made with the purpose of developing efficient milling cutters have clearly demonstrated the following advantages of the coarse teeth

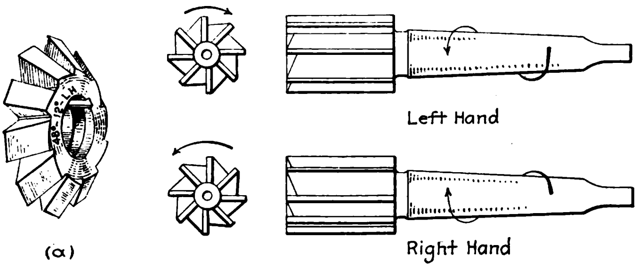


FIG. 186.—R. H. and L. H. cutters; (*a*) shows 48°–12° L. H. double angle cutter.

cutters with the increased spiral, as compared with the previously recognized standards:

1. Ample chip space.
2. Increased strength of tooth.

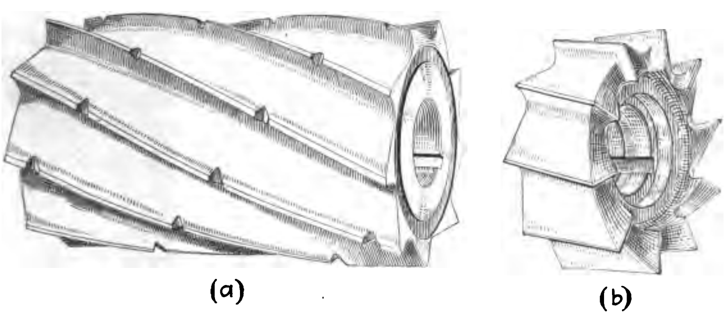


FIG. 187.—Coarse tooth milling cutters.

3. More nearly perfect shearing cut, that is, less power required to remove a given amount of metal.

4. Free cutting action (larger chip per tooth) eliminating tendency of cutting edge to scrape or slide instead of cut, causing less friction and consequently less heat.

5. Longer life, less need for grinding; also may be groun greater number of times and with less time spent at each grinding.

6. Notches with clearance both sides.

These advantages may be summarized thus: These cutters are capable of much greater production than the older style of cutter, and use comparatively less power.

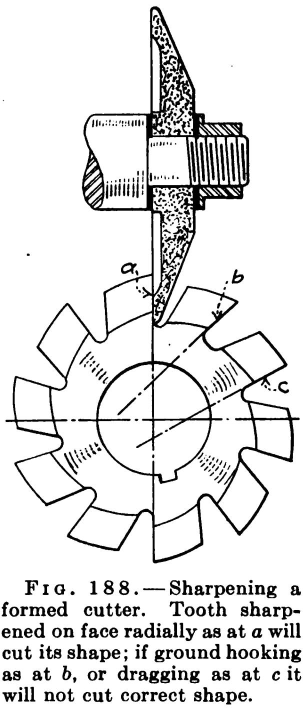


FIG. 188.—Sharpening a formed cutter. Tooth sharpened on face radially as at *a* will cut its shape; if ground hooking as at *b*, or dragging as at *c* it will not cut correct shape.

162. Sharpening Cutters.—A milling cutter, like any other cutting tool, will do good work when it is correctly sharpened and under proper conditions will do a considerable amount of work before it is noticeably dull. If, however, it is operated when noticeably dull, the excessive friction generates heat enough to soften the teeth, and it will soon become *very dull* and possibly ruined.

To sharpen a dull cutter takes only a few minutes and reduces each tooth only a small amount. To sharpen a *very dull* cutter takes a long time and a large portion of each tooth must be sacrificed. "Keep cutters sharp."

Formed cutters are sharpened by grinding the face of the tooth radially, and every tooth alike. If one tooth is ground less than another it is longer and consequently cuts more than its share and dulls quickly. When not ground radially they are either "hooking" as at *b* (Fig. 188) or "dragging" as at *c*. In either case the true profile is not produced because the teeth are so made that the outline of the cutting edge is correct only when the teeth are ground radially.

Cutters with saw teeth or inserted teeth are sharpened by grinding the lands. The angle of tooth clearance is a very

important consideration. The clearance is the amount the top of the tooth (the land) is relieved (or "backed off") so that this part of the tooth will not rub on the work after the cutting edge has passed. If the clearance is too great the cutter dulls rapidly and if not enough the cutter rubs and does not cut. The proper clearance angle should be about 7° for cutters under 3" in diameter, and about 5° for those over 3". The clearance on end teeth (and side teeth) should be about 2°, and in order to avoid the tendency to drag and thus score the surface of the work they should be ground .001 or .002 in. lower toward the center. That is, placing a scale across the diameter of the cutter would show the end (or face) to be slightly concave.

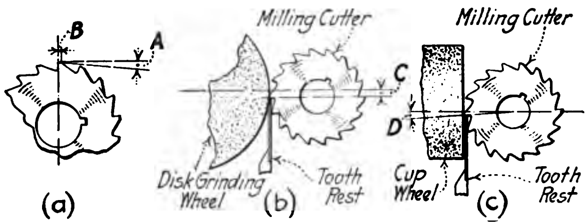


FIG. 189.—Clearance grinding on milling cutters.

The angle of tooth clearance of a cutter is measured from a line at right angles to the radial as in the figure, *A* representing the angle of clearance, *B* the land of the tooth. Milling cutters under 3" in diameter are usually given a clearance of 6° or 7°; those 3" and over 4° or 5°. The practical mechanic often determines if the milling cutter has sufficient clearance by bending a flexible scale around a portion of the circumference. He makes sure that the tooth has clearance (if the scale touches the cutting edges only) and he judges the amount of clearance by the opening between the land and the scale.

To obtain clearances on cutter when grinding with *disk wheel* as in (*b*). Set tooth rest at height of work centers, and center of wheel spindle in same plane. (A center height gage is usually furnished with the machine, if not a surface gage may be used.)

Then lower the table the amount for clearance, as at *C*, which may be found by the following rule: Multiply, .0088 (the constant for 1° clearance) by the clearance angle and this product by the *diameter* of the *grinding wheel.*

Example: Find the distance to lower the table for 5° clearance angle, diameter of grinding wheel 6 inches. Solution: $.0088 \times 5 \times 6 = .264''$.

To obtain clearances on cutter and reamer teeth when grinding with a *cup wheel* as in (*c*). Fasten tooth rest to wheel head and adjust to height of work centers, using center height gage. Then raise the table the amount for clearance, as at *D* which may be found by the following rule: Multiply .0088 (the constant for 1° clearance) by the clearance angle and this product by the *diameter* of the *cutter* or *reamer*. Example: Find the distance to raise the table for 4° clearance, diameter of cutter 5". Solution: $.0088 \times 4 \times 5 = .176''$.

The various manufacturers of cutter grinders furnish booklets illustrating and explaining the operation of their machine. The operator, the beginner especially, will find such information very helpful. The rules given in connection with Fig. 189 are fundamental and applicable in any cutter grinding machine.

When grinding cutters use a soft wheel of medium grain (see "Grinding Wheels"). Keep the wheel clean and true and take light fast cuts to avoid drawing the temper of the cutter.

HOLDING THE CUTTER

The revolving main spindle of the milling machine carries with it the milling cutter. The cutter may be held in several different ways. Perhaps the method most commonly used for holding the milling cutter is by means of an arbor.

163. Milling machine arbors (Fig. 190) are made in various lengths and in standard diameters of ⅞, 1, 1¼ and 1½ in.

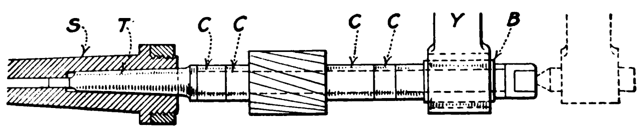


FIG. 190.—Milling machine arbor in position.

Milling machine arbor. *S*, machine spindle; *T*, taper shank of arbor; *C*, collars. The outer end of the arbor is threaded to receive the nut. In machines, Brown & Sharpe for example, where cutter normally runs left hand the arbor and nut are threaded left hand. Thus the pressure of the cut does not tend to loosen the nut. *B*, bushing for journal bearing in bearing support or yoke *Y*. Dotted lines show yoke center in end of arbor.

The shank is made taper to fit the taper hole in the spindle, and the other end is threaded to receive a nut. The remaining portion of the arbor is made cylindrical. Collars are fitted freely over this part of the arbor and by means of the nut one or more cutters may be clamped between the collars. The collars being of different lengths and removable, permit of cutters of various lengths (or thicknesses) being clamped and also permit of locating the cutters in the desired position on the arbor. The arbor is supported by the yoke from the over arm either by a center or in a bearing in the yoke. The

bushing *B* which forms the journal in the outer bearing for supporting the arbor is of somewhat larger diameter than the collars and is ground to fit a bronze bearing in the arbor yoke. To avoid spring of the arbor, the bearing should always be located as close to the cutter as will allow the yoke to clear the work and the vise or fixture that holds the work. For the same reason, the center should not be used unless it is impracticable to use the bushing in the bronze bearing.

Some arbors have a tang on the shank which fits a slot in the spindle. They are removed by means of a knock-out rod similarly as a live center is removed from a lathe spindle.

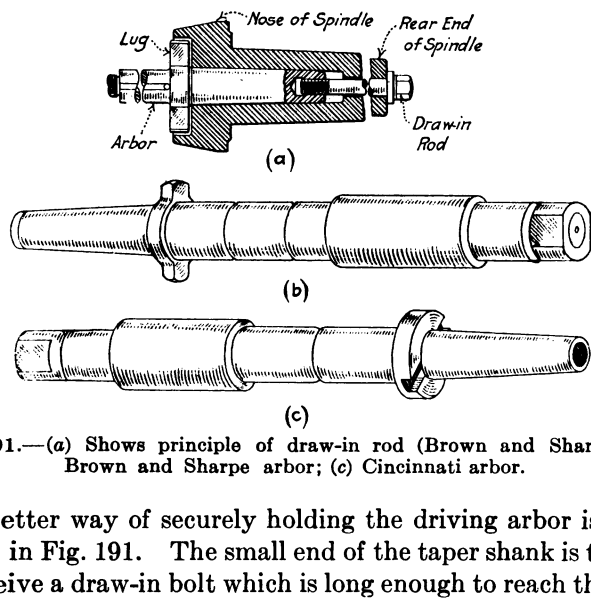


FIG. 191.—(*a*) Shows principle of draw-in rod (Brown and Sharpe); (*b*) Brown and Sharpe arbor; (*c*) Cincinnati arbor.

A better way of securely holding the driving arbor is illustrated in Fig. 191. The small end of the taper shank is tapped to receive a draw-in bolt which is long enough to reach through the spindle and serves to draw the shank firmly into the taper hole. To drive the arbor it is provided with positive-clutch-like lugs or projections which fit into the groove milled across the end of the spindle (as in the Brown & Sharpe machine), *a* and *b*, (Fig. 191), or an enlarged flanged portion at the large end of the taper shank is recessed to fit over the keys at the end of the spindle (as in the Cincinnati machine, *c*, Fig. 191). In either case it is unnecessary to drive the arbor

home as with the tanged arbor; merely turn the draw-in bolt tight enough to securely hold the arbor in place. To remove it loosen the draw-in bolt part of a turn and tap lightly on the head. The ends of the spindles of Brown & Sharpe and Cincinnati machines are shown in Fig. 194.

The friction between the collars and cutters is sufficient to hold the cutter for light cuts, but for heavy duty, the cutter should be keyed. Arbors are usually splined for keys.

164. Holding End Mills.—End mills (Fig. 177) up to 2 in. diameter are usually made solid with the shank, the shank being generally Brown & Sharpe standard taper of a size to conform to the size of the cutter.

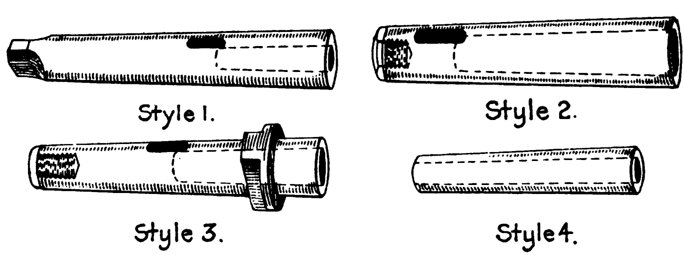


FIG. 192.—Milling machine collets.

Unless the size of the shank is the same as the taper hole in the spindle, it is necessary to use a *collet* (Fig. 192) to hold the cutter. A milling machine collet is the same sort of tool as the drill press *socket* or a lathe *sleeve*, in that it serves the purpose of stepping taper sizes. The taper, however, is *not* the same.

165. Holding Straight Shank Cutters.—End mills with straight shanks *e* (Fig. 177) may be used if a special holding chuck is provided. Their cost is somewhat less than that of taper shank mills of the same size, and in the smaller sizes they are very satisfactory. Most Whitney keyway cutters are made with straight shanks. Figure 193 shows a keyway cutter held in the spring chuck or "spring collet."

166. Holding Face Milling Cutters.—The larger end milling cutters are generally known as face milling cutters. Face

milling cutters are usually mounted directly on the end of the milling machine spindle, in such a manner as to firmly hold and positively drive the cutter, and also to make removal of the cutter easy. Two methods of holding face mills are illustrated in Fig. 194.

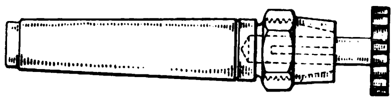


FIG. 193.—Whitney key cutter chuck. The front end of the arbor is slightly tapered for a short distance and then threaded, and the hole in the nut is correspondingly tapered and threaded. The end of the arbor is split by three equally spaced slots and tightening the nut serves to grip the shank of the cutter. This type of chuck is often called a spring chuck.

Brown & Sharpe Method.—The cutter is drawn directly on the taper nose of the spindle by a cutter driver and draw-in bolt. One part of the cutter driver fits into a slot in the face of the cutter and another portion in a slot or recess

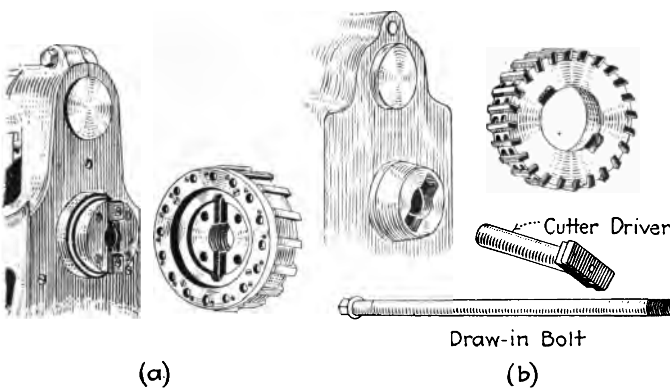


FIG. 194.—Holding face mills.
(*a*) Cincinnati method. (*b*) Brown & Sharpe method.

in the face of the spindle. The shank of the driver is threaded in the end to receive the draw-in bolt which extends through the spindle and when tightened serves to draw the cutter on the spindle. The taper on the nose of the spindle serves to

center the cutter but is steep enough to preclude all possibility of the cutter "freezing."

Cincinnati Method.—The end of the machine spindle is shouldered or "flanged" and fitted with hardened keys arranged radially. One size of flanged spindle end is used on all sizes of machines of this type, therefore the same cutter may be used on machines of different sizes. The back of the cutter is counterbored to fit the flanged end; this centers the milling cutter. Four cap screws hold it in place. A groove milled in the back of the cutter fits over the hardened keys which

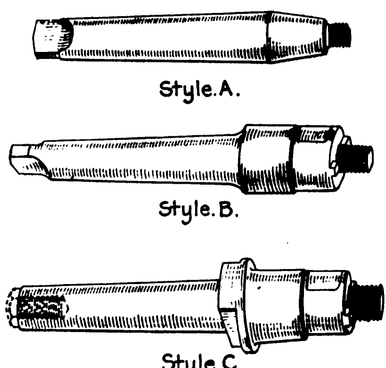


FIG. 195.—Screw-on cutter arbors.

are fastened to the spindle flange and which serve to drive the cutter.

Either of the above methods are much superior to the older style of threaded nose spindle on account of the stronger drive and greater ease in both placing and removing the cutter. An adapter threaded inside to fit the nose of the older type spindle, and turned on the outside to fit the hole in the cutter, may be used with the later type of cutter if necessary.

167. Screw-on Cutters and Arbors.—Many of the small cutters such as corner rounding, convex and concave cutters, and cutters for fluting the smaller sizes of end mills, reamers, counterbores, etc., are often of the form of screw-on cutters. The hole is tapped 3/8–16 or 1/2–16 and the screw arbor

(Fig. 195) is threaded on the end to receive the cutter. In order that the cutter will not loosen and come off the arbor during the cut and thus spoil the work, right hand cutters (see paragraph **160**) have right-hand threads and left-hand cutters have left-hand threads. Screw-on cutter arbors are usually made with No. 7 B. & S. taper shanks and fit into a collet.

Questions on Milling Cutters

Obtain from the tool-room an example of each of the following milling cutters: Spiral mill, metal slitting saw or slotting cutter, side mill, angular cutter and end mill.

1. How large in diameter is this spiral mill? How long is the cutter? How wide is the face?

2. Roll the cutter fairly hard on a piece of paper and measure the angle of the tooth with the axis of the cutter. What is the angle of the spiral of the cutter?

3. What is a spiral milling cutter used for?

4. What is the advantage of the spiral tooth?

5. Lay the edge of a scale across the face of the slotting cutter. Why is it not made straight? Is the end of the spiral mill straight? Why?

6. What is meant by a plain milling cutter? Is the slotting cutter a plain milling cutter? Explain. Is the spiral mill a plain milling cutter?

7. What is the general shape of the tooth of the slotting cutter? Of the spiral mill?

8. How much clearance is given the cutting edges of these cutters? Why not more? Why not less?

9. Lay the edge of a scale across the face of the side mill, and look under it. Have the side teeth any other clearance than the tooth clearance? Give reason.

10. Is the length of the hub equal to the width of the face of the side mill?

11. If it is desired to use a pair of these side mills for straddle milling will a collar be used which is the same thickness or length as the distance required between cutting surfaces? What thickness will be used?

12. Why should you think it advantageous to have thin metal collars or "washers" or "spacers" for obtaining the correct distance between straddle mills?

13. Do the side teeth of a side mill cut when straddle milling? Of what use are they?

14. Could a side mill be used efficiently for cutting on the face only? Give reason.

15. What is meant by an inter-locking cutter? How is such a cutter advantageous when milling slots of an exact width?

16. Examine the angular cutter. What angle is it? Is it so marked?

17. Is it a right-hand or a left-hand cutter? Is it so marked?

18. State how you can select a R. H. or L. H. cutter that is not marked.

19. What is a double-angle cutter? What do you mean by a 90° cutter? 60° cutter?

20. What is the shape of a cutter for milling spirals? What is the difference between a 48°–12° cutter and a 53°–12° cutter?

21. What are the general characteristics of an end mill?

22. What is the largest size of solid end mill usually made? Why?

23. How are end mills of the larger sizes made? What is the advantage?

24. What is the cutter of still larger diameter with teeth on the face called?

25. When is an end mill useful for plain milling?

26. Is it advantageous to have the peripheral teeth of an end mill 1¼ in. diameter cut spirally? Of an end mill ⅝ in. diameter?

27. What is the reason you cannot use an end mill as a drill?

28. What advantage has an end mill with center cut?

29. What is a cotter-mill? What is the advantage of having only two teeth?

30. How do you distinguish a right-hand end mill?

31. Of what kind of material is the body of an inserted tooth cutter made? Of what kind of steel are the teeth made? What is the difference in the price of these materials?

32. If one tooth of a solid cutter breaks does it effect the efficiency of the cutter? Can a solid cutter with a broken tooth be repaired? How may such a repair be made on an inserted tooth cutter?

33. Can a worn out solid cutter be re-made to original size and shape? How can an inserted tooth cutter be re-made? What would be the cost of re-making compared to a new solid cutter?

34. Is it easy to harden a large solid cutter? Can you guarantee it will not crack?

35. Is it easy to harden teeth for an inserted cutter? Suppose one or two of the teeth are cracked what would you do?

36. How are you able to shim under the teeth of an inserted cutter if necessary? When may this be advisable?

37. State all the advantages you believe an inserted tooth cutter has.

38. Obtain from the tool-room a formed cutter: a gear tooth cutter will do. What is meant by a formed cutter?

39. Can you explain how, in the process of making the cutter, the teeth of the cutter are formed to the irregular shape and "backed off" at the same time?

40. When the cutter is being formed and relieved (backed off) the forming tool is held exactly on center. Why is this necessary?

41. What part of the formed cutter is ground when necessary to sharpen the cutting edge?

42. How should the formed cutter be ground to preserve the original shape of the cutting edge? Why?

43. When should a formed cutter be ground? Why? How much of the tooth may be ground without destroying the original shape of the cutting edge? Why?

44. Why is a double-angle cutter or cutter for cutting spiral mills or a reamer-grooving cutter made as a formed cutter more efficient than the saw-tooth cutter?

45. Are you able to find any other shapes of formed cutters either larger or smaller?

46. How many reasons can you give for the efficiency of the formed cutter.

47. What is a fly cutter? When is it advantageous to make and use a fly cutter? How is a fly cutter held?

48. When making the fly cutter, what is the object of turning (forming) the cutter with the liner behind it? Ans. To give it clearance.

49. The tendency of the manufacturers is to substitute wherever possible for the radial face on the teeth of milling cutters a face having a rake of about 10°. Further, since high-speed steel has largely superseeded carbon steel for milling cutters, the tendency has been toward coarser teeth. What is the advantage of rake on milling cutter teeth?

50. What are two advantages of the coarse tooth on milling cutters?

51. Are formed milling cutters given a spiral cut? Give reason. Are they given rake? Give reason. Do they have coarse teeth?

52. Why do the longer spiral milling cutters have nicked teeth? How is the nick given clearance? Why is it given clearance?

53. Why is a right-hand spiral out on a left-hand end mill?

54. Why are small diameter cutters made with shanks?

55. What is the reason for making some cutters screw on a shank?

56. Why does a left-hand screw-on cutter have a left-hand thread?

57. What is a T-slot cutter? Why do you have to remove the central portion of the T-slot before using the T-slot cutter?

58. If you go to the tool-room to obtain a milling cutter, how do you specify the cutter you wish?

59. It may be stated that half the life of many cutters is wasted by running when dull. Explain in detail.

60. How many of the various kinds of cutters listed in a catalogue of cutters are you able to find and examine?

CHAPTER X

SPEED FEED AND CHIP

168. Introduction.—The output of a machine is dependent among other things upon the efficiency of the cutting tool. To remove a given amount of metal the cutting tool is efficient only when operated at the proper depth of cut and the proper speed and feed. Therefore in the matter of production the question of cutting speeds and feeds is of extreme importance to the employer. And in the matter of making good, a knowledge of the conditions that enter into the question "What is the right speed feed and chip for this job?" is of extreme importance to the progressive machinist.

As the work is fed against the revolving milling cutter each tooth peels off a chip. The amount of metal removed in a given time depends on the width of the cut, the depth of the cut, the thickness of the chip (fine feed or coarse feed) and the speed of the cutting edge through the metal (cutting speed.) The width of cut, the depth of cut, the feed and the speed are all variables. The feed and chip are more or less matters of judgment and conditions governing them will presently be explained, the cutting speed, however, is governed by practically fixed conditions.

169. Cutting Speed.—As the work is fed against the revolving cutter, the rate at which the chip is cut is the cutting speed. In other words the cutting speed of a milling cutter is the speed in *feet per minute* of the cutting edge of a tooth as it peels off its chip.

Taking the cut causes friction between the cutter and the work, and friction generates heat. When a cutter is overheated the temper is destroyed and in many cases the cutter is ruined. The heat generated in cutting any material depends upon the hardness and toughness of the material being cut, the harder and tougher the metal, the more the heat generated and, therefore, the slower the cutting speed must be.

Because of its peculiar properties a cutter made of high-speed steel may be run at double the speed (or more) of a carbon-steel cutter without spoiling the temper, consequently the kind of material from which the cutter is made is an important factor in determining the cutting speed.

From the above it will be observed that of the variables entering into the efficient action of a milling cutter, the cutting speed has a more or less *fixed value,* that is, the cutting speed depends (1) on the kind of material being cut, and (2) the kind of steel from which the cutter is made.

Iron castings of different chemical compositions and steels of different manufacture vary so much in their hardness, especially the carbon steels and the alloy steels, that it is impossible to offer a table except for average cutting speeds. What would be a safe speed for one kind of tool steel, for example, would utterly ruin a cutter in a short time on another kind of tool steel. The *average* cutting speeds used in machine shop practice when machining with carbon steel cutting tools are:

25 feet per minute for tool steel
35 feet per minute for machine steel
40 feet per minute for cast iron
100 feet per minute for brass
(Double or more for high-speed cutters)

It is advisable to start with a comparatively slow speed and advance this speed from time to time, if it is found possible to do so without stopping too often to sharpen (or change) the cutter. The cutting speed for wrought metals and steel may be increased considerably by using a good flow of cutting lubricant since it reduces friction and helps to carry away the heat. Cast iron is milled dry.

170. Cutting-speed Calculations.—The cutting speed of a milling cutter is the speed in *feet per minute* of a point on the *circumference* of the cutter. The number of revolutions per minute necessary to give the required cutting speed depends on the circumference of the cutter. Naturally, for a given cutting speed, the smaller the cutter the faster it must run.

If the circumference of a cutter is 1 foot and a speed of 40 feet per minute is required it will take 40 r.p.m. If the circumference were ½ foot it would take 80 r.p.m. In either case it is the cutting speed divided by the *circumference in feet* of the cutter.

Now in machine-shop practice, the circumference of the work, milling cutters, drills, etc. is never given, the *diameter* is used to express the size, further all diameters are expressed in *inches*. To find the *circumference in feet* of a cutter whose *diameter in inches* is known, multiply the diameter by 3.14 to get the circumference in inches and divide the product by 12 to reduce to feet. The diameter multiplied by 3.14 and this divided by 12 is equal to .26 times the diameter. $(3.14 \div 12 = .26)$ Instead of multiplying the diameter by 3.14 and dividing by 12 in every problem it is much quicker to multiply the diameter by .26. Further, since .26 is so nearly ¼ it may be stated that for all practical purposes the revolutions per minute may be calculated by the following:

RULE.—To obtain the revolutions per minute necessary to give the required cutting speed, divide one-fourth of the diameter into the cutting speed.

$$\text{Formula: r.p.m.} = \frac{C.S.}{.25D}$$

Example.—It is desired to mill a piece of machine steel at a speed of substantially 35 feet per minute with a cutter 2 in. in diameter. What number of revolutions per minute of the cutter is necessary?

Solution.—$\text{r.p.m.} = \dfrac{35}{.25 \times 2} = \dfrac{35}{.5} = 70$ r.p.m. *Ans.*

Set the spindle speed to as near 70 r.p.m. as possible.

MILLING MACHINE FEEDS

171. Definitions of Feed.—(1) Theoretically the feed of a milling cutter is the thickness of the chip per tooth of the cutter, that is, the distance the work advances against each succeeding tooth of the cutter. (2) In cone-driven machines the amount of feed is dependent on the spindle speed and is often rated as the distance the table moves per revolution of

the spindle. (3) In milling machines having a constant speed drive, the feed mechanism is usually independent of the number of revolutions of the cutter and in these machines the feeds are arranged to move the table a certain distance per minute. For this reason it is now quite proper to speak of the milling machine feed as so much per minute, as 1 in. feed, or 10 in. feed, etc., meaning that the table feeds that distance in 1 minute. The particular definition of feed is unimportant, the question is one of *proper amount.*

172. Conditions That Govern the Amount of Feed.—The problem of proper milling-machine feeds offers one of the most interesting and one of the least understood questions in machine tool operation. There are so many conditions that enter into the question of feeds, that hard and fast rules are impossible. The depth of cut and the width of cut, also whether it is a roughing cut or a finishing cut, in other words, the amount of metal to be removed and the appearance desired are factors. Further, the diameter of the cutter; the number of teeth in the cutter; the proportion of thickness to the diameter; the speed at which the cutter is revolving; the way in which the cutter is held; the power and rigidity of the machine; and the rigidity of the work are all factors which must be taken into consideration in obtaining efficient feed.

173. Analysis of Cutting Feed Conditions.—First, it will be understood that in any operation of cutting metal a considerable force is exerted against the piece being cut and a reaction against the cutter itself; and that the amount of metal removed (feed and chip) is in proportion to this force. Therefore, the proper depth of the cut (chip) and the proper amount of feed depend to a certain extent on what the other is, and in addition, both depend on the power and rigidity of the machine itself.

Second, the correct chip and feed depend on the strength of the cutter and the rigidity with which it is held, and the strength of the work and the manner in which it is held. For example, a slender end mill or a thin slitting cutter cannot be given heavy duty; neither should a frail piece of work or a

piece held in such a manner that it may spring or bend be given a heavy chip or feed.

Third, the teeth of the coarse tooth cutter are proportionately stronger than the smaller teeth, the chips wash out more readily and the cutting lubricant keeps the cutting edge cooler. For these reasons a heavier chip or feed may be taken with a coarse tooth cutter.

Fourth, while the coarse feed removes metal faster, the appearance and accuracy of the surface are not as good as is desirable for finished work, therefore, a finer feed is used for finishing.

An example will serve to show the action of a milling cutter. A cutter 3 in. in diameter cutting 35 feet per minute will make 45 r.p.m. ($35 \div (3 \times .26) = 45$). If this cutter has 12 teeth, then 12 chips will be cut each revolution and 45 multiplied by 12, or 540 chips per minute. If the feed is 6 in. per minute and 540 chips are cut per minute each chip is .011 thick. This is theoretical, no milling cutter runs exactly true, but even so, probably no chip will be over 1/64 in. thick.

In ordinary milling practice, when using a fair sized carbon steel formed cutter on machine steel, with a good flow of cutting compound, a feed of 4 or 5 in. per minute is not excessive. With a coarse tooth spiral cutter a feed of 10 in. per minute is not too much to try and may probably be increased. Since cast iron must be cut dry the feed is reduced about one-third. High-speed steel cutters running at about double the speed of carbon cutters will stand up well under practically double the feeds (*in inches per minute*) of the carbon cutter.

The general tendency is to *over speed* and *under feed* a milling cutter. The reason for most of the too quickly dulled cutters is too much speed, and rarely if ever too much feed. It will be well for the beginner to go fairly slow at the start and avoid spoiling the cutter or work or possibly both, but to keep right on the job with the idea of advancing the speed or feed as much as possible with due regard to the time it takes to sharpen the cutter.

174. The Size of the Chip.—On most work no more than two cuts are required, a roughing cut and a finishing cut. If it happens that two or more cuts are necessary the rule is to take, for the roughing cuts, a coarse feed and about all the chip the machine, cutter and work will stand.

As in shaper or planer work care must be taken when milling cast iron that the edges at the end of the cut are not broken away below the finished surface. Milling fixtures, special vise jaws, etc., for manufacturing are designed to back up the metal at this point thus overcoming the tendency of the corners to break off, but in many special jobs it may be necessary to feed carefully, by hand, toward the end of the cut.

175. The Finishing Cut.—Remember that attention to the slogan "keep cutters sharp" is one of the main factors in good milling; bear in mind that a surface that has been milled with a good sharp cutter is as accurate as a filed and polished surface. Also it is easier and quicker and therefore cheaper to mill to size than to finish by polishing.

When it is advisable to make two cuts, a roughing cut and a finishing cut, leave at least $\frac{1}{64}$ in. for the finishing cut. In any machine a cutting tool will do better work and last longer if the edge has a chance to get under the chip, where it has less tendency to rub. That is, there must be enough of a chip to hold the cutting edge of the tool down into the work.

There is always spring in every milling operation. If the feed is stopped while the cutter revolves on the work, the surface will be defaced by an under cut. *Do not throw out the feed on a finishing cut.*

For the same reason as above if a cut just made is run back under a revolving cutter, the work will be marked each revolution of the cutter. Stop the cutter before running back or else lower the work a trifle.

No milling cutter runs exactly true, and consequently some few teeth do a major share of the cutting. It may be practicable, especially when finishing, to give the cutter part of a turn on the arbor; this often serves to bring the sharper teeth into play.

176. Lubricating the Cutter.—A lubricant should always be used when milling steel or wrought metals. It serves to wash away the chips, produce a better finish, keep the cutter cool and give a longer life to the cutting edge. A good quality of lard oil is considered best. There are, however, several specially prepared cutting compounds in the market which are cheaper than lard oil and for most operations serve the purpose of a cutting lubricant as well as does lard oil. Provision is made in all milling machines to save the lard oil or cutting compound and use it over and over again. The manufacturing milling machines are equipped with a pump to effect the circulation and provide a steady stream of the size and force desired. The smaller machines and the universal machines are not usually equipped with pumps, so the cutting compound is held in a small can from which it is allowed to drop on the cutter through a pipe. In any event the cutting compound should be used freely but should not be wasted, that is, should not be allowed to drench the machine and the floor. Remember cast iron is always machined dry.

177. Direction of Cutter and Feed.—It is usually considered better practice to feed the work against the cutter as shown at *a* (Fig. 196) rather than with cutter as shown at *b*. There are two good reasons for this: When the work is fed in the opposite direction to that in which the cutter revolves the teeth do not come in contact with the scale, and also the back lash in the feed screw is taken up against the force of the cut preventing any tendency of the cutter to "dig."

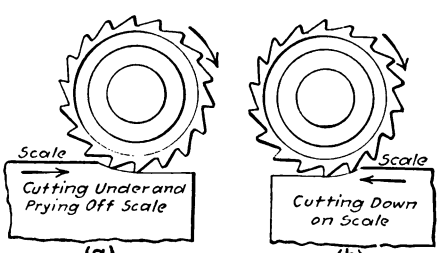


FIG. 196.

NOTE.—As an exception to the above; when cutting off stock and when milling comparatively deep or fairly long slots there is less tendency for the cutter to crowd sidewise

thus making a crooked cut and possibly breaking the cutter, if the slotting cutter is operated as shown at *b* (Fig. 196).

The direction of the cutter with regard to the manner in which the work is held is important. (1) The arrangement should be such that any tendency of the work to spring will be in a direction away from the cutter. (2) The arrangement should be such that there will be no tendency to loosen or displace the work.

Caution.—To run a cutter "backwards" will break the teeth. Be very sure the cutter is mounted on the arbor to revolve in the proper direction and *that the machine spindle is arranged to revolve in that direction.*

Questions on Speed, Feed, and Chip

1. What conditions govern the cutting speed of a milling cutter?

2. What is the difference between revolutions per minute and feet per minute?

3. What is the average cutting speed for the different metals used in machine construction when using carbon-steel cutting tools?

4. How many revolutions per minute should a carbon-steel milling cutter 3″ in diameter be run to cut machine steel? Tool steel?

5. What is the formula for calculating revolutions per minute of milling cutters having given the diameter of the cutter and the required cutting speed?

6. Having calculated the revolutions per minute how do you set the spindle speed? Can you set it exactly right? Give reason.

7. How do you define milling machine feed?

8. State at least six conditions that govern the amount of feed in milling.

9. How many different rates of table feed may be obtained in the machine you are running?

10. Generally speaking, how much of a chip may be taken in the roughing cut?

11. State three reasons why a dull cutter should not be used.

12. How much should be left for a finishing cut? Why?

13. What would happen if the finished surface is run back under the revolving cutter? How is this avoided.

14. What is the value of cutting lubricant?

15. What is the general rule concerning the direction of the cutter and the feed? What are the reasons? State an exception to this rule.

CHAPTER XI

TYPICAL MILLING SET-UPS AND ELEMENTARY OPERATIONS

HOLDING THE WORK

178. Various Methods of Holding Work.—Several T-slots, running the length of the work table, finished to a standard width, and exactly parallel with the travel of the table, are provided for the purpose of locating and clamping the work itself, or any devise for holding the work.

The following list of methods of holding work in the milling machine will serve to give some idea of the adaptability of the machine and also of its value in manufacturing and in general machine shop work and tool making. The figures referred to in this list are mostly for the purpose of illustrating other details but since they show also some of the methods of holding work it may prove helpful to refer to them in this connection.

The work may be held in a special fixture (Fig. 168).

It may be clamped directly to the table (Fig. 166).

It may be fastened to an angle plate or similar tool which is clamped to the table (Figs. 163, 164).

It may be held in a vise (Figs. 159, 160, 162, 165).

It may be held between the centers of the index head and footstock (Figs. 154, 158, 167).

If provided with a taper shank it may be held in the index head spindle or in a collet which fits the index head spindle (Fig. 169*a*).

It may be held in a chuck which screws on the index head spindle (Figs. 219 and 220) or in a drill chuck or a special chuck the shank of which fits the taper hole in the head spindle.

It may be held on a face plate which screws on the index head spindle.

When the work is held by means of the index centers, using

any of the last four methods suggested, it is usually for the purpose of *indexing*. The index head and the methods of indexing are explained in Chap. XII.

179. Milling Machine Fixtures.—In manufacturing, where large numbers of pieces are to be milled alike, it is customary to hold the work in fixtures. A milling fixture is a special device for accurately locating and securely holding one or more pieces while the desired cut is being made. It is usually clamped to the table.

Fixtures are made to hold work for various operations in any of the standard machine tools but are used most in milling machine work. The purpose of a fixture is to make it easy for the operator to locate the work accurately, support it properly and hold it securely, and withall quickly.

In addition to the locating, supporting and clamping features of the fixture, setting pieces or gage points or both are often so valuable as to be almost necessary. That is, when a fixture is used on a planer or on a milling machine or elsewhere, if certain surfaces of the fixture corresponding to the important surfaces to be machined on the work are provided as permanent features of the fixture, they will save a lot of time and trouble in setting the cutting tools and in gaging the work. To avoid any tendency of cutting into the setting piece it may be made somewhat undersize and a suitable thickness gage used when setting the cutter.

Fixtures vary in design all the way from special parallel pieces, suitable blocks, or purposely shaped vise jaws, each possibly provided with locating pins, to very expensive complicated mechanical devices. The use of fixtures is more particularly manufacturing work and the making of fixtures is tool-making. For illustrations and descriptions of typical milling fixtures the reader is referred to "A Treatise on Milling" published by the Cincinnati Milling Machine Co. and "Treatise on Milling Machines" published by Brown Sharpe Manufacturing Co.

180. Clamping Work to the Table.—Certain principles of clamping work to the table, to an angle plate, etc., have been

explained in the chapter on "Planer Work" beginning page 143. It is suggested that the student refer to these pages.

181. Holding in a Vise.—For holding a large variety of work a vise may be most advantageously used. Vises are made in many sizes to correspond with the size of machine on which

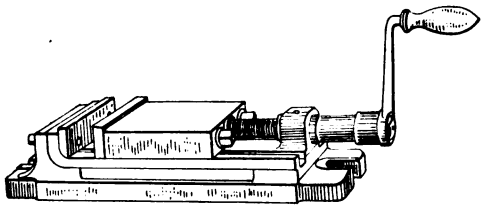


FIG. 197.—Plain vise.

they are used, or if desired, to accommodate a wide range of work on the same machine. There are three distinct kinds of vises; the *plain* vise, the *swivel* vise, and the *universal* vise.

The Plain Vise (Fig. 197).—For milling cuts parallel to the length of the work or at right angles to the length, the plain vise is best. It is simple and substantial and holds the work close to the table. Key slots at right angles and removable keys are provided, by means of which the vise may be quickly set either exactly lengthwise or crosswise on the table. A very efficient holding device can be cheaply made if special jaws are provided having the necessary locating pins or stop pins, and possibly having a profile to correspond with the outline of the cut (see Fig. 165 also Fig. 203).

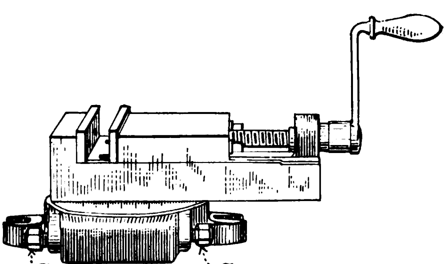


FIG. 198.—Swivel vise. To swivel the vise loosen the screws *a*.

The Swivel Vise.—If the keys are removed from the bottom of a plain vise it may be set in any position on the table by means of a protractor. A *swivel vise* (Fig. 198) is, however,

much more convenient. This vise may be swiveled to any angle and rigidly clamped on its base, the position being indicated by graduations in degrees. It is a very useful all around vise but is not as rigid as a plain vise.

The Universal Vise (Fig. 199).—The vise contains two complete circle swivels separated by an adjustable angle plate or "hinged knee," all three of which are graduated to indicate the position in degrees. It may be set and rigidly clamped

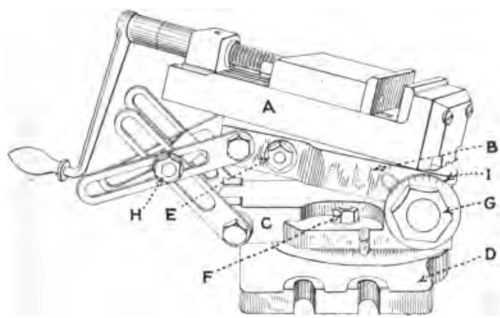


FIG. 199.—Universal vise. The vise proper *A* may be swivelled on the upper part *B* of the hinged knee. (First loosen *E*.) The lower part *C* of the knee may be swivelled on the base *D* (First loosen binding bolts *F*). The upper part of the hinged knee may be set at any angle from a horizontal to a vertical position, and clamped by tightening the nut *G* on the bolt which forms the hinge pin and the bolt *H* at the joint in the braces. Graduations in degrees on dial *I* indicate the angular setting of the hinged knee. Graduations in degrees are provided also to indicate the position of *A* on *B* and the position of *C* on *D*.

at any angle with the table or the machine spindle. To one who is familiar with its advantages, this vise seems almost indispensable in tool-making and model work. It is not meant for heavy milling.

SETTING UP THE MILLING MACHINE

182. Aligning and Squaring the Holding Tools and Work.—It is not always practicable to use the keys for locating the plain vise; perhaps the keys may be too large or too small or not in the position desired. Moreover it is not always wise to depend on the graduations of the swivel vise for accurate setting. Further, it is very often necessary to align a

surface or check a set-up by other means than either the key or the swivel graduations, for example, an angle plate or a similar tool or some previously finished surface of the work. One of the best ways to set the fixed vise jaw, or other surface to be aligned, exactly parallel with the direction of the cut, or exactly at right angles to it, is by means of an indicator as shown in Fig. 200. First set the surface to be aligned in position as nearly as may be judged, then having the contact point of the indicator against this surface, tighten the body or shank of the indicator between two collars on the arbor, and moving the table lengthwise or crosswise as the case may be, note the movement of the indicator needle and adjust accordingly.

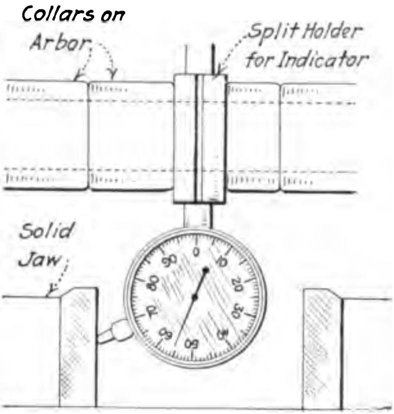


Fig. 200.

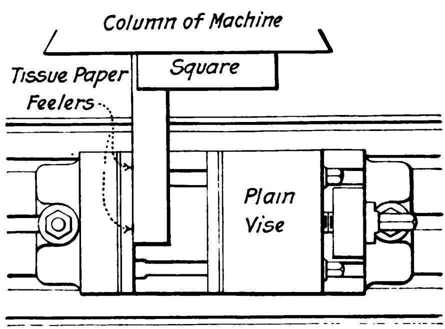


Fig. 201.

If an indicator is not available, a square may be used for setting at right angles by placing the beam of the square against the finished face of the column, and the blade along the vise jaw or other surface to be squared (Fig. 201).

For the reason that feeling is at times more nearly accurate than seeing, feelers of tissue paper are often placed between the surface to be tested and the blade of the square as shown in the figure. If about the same force is required to pull either feeler, the surface is assumed to be square.

Parallels may be used to set the angle plate parallel with the cut. Clamp the angle plate fairly tight in its approximate position and then lightly squeeze one or more clean parallels between it and the face of the column (Fig. 202). This will bring the surface of the angle plate in line with the edge of the parallel; then clamp the angle plate securely.

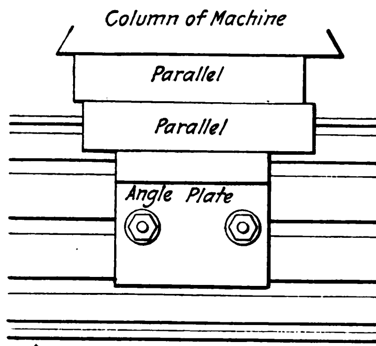


FIG. 202.

A vise may be aligned in a similar manner, by clamping a parallel in the vise so that it projects somewhat above the jaws and lightly squeezing one or more other parallels between it and the column. If for any reason the table of a universal milling machine has been set at any angle it may be accurately re-set by using a parallel as explained above between the side of the table and the column. As a matter of fact it will be wise to set the table exactly in this manner before the vise or angle plate is set. Do not depend on the swivel graduations for extreme accuracy.

The above methods are the most accurate methods but if the milling arbor runs true or very nearly true the vise or angle plate may be set parallel or square enough for the average job by (1) arranging the face to be set *parallel* against the arbor or (2) arranging the face to be set *square* against the blade of a square, the beam of which is held against the arbor.

183. Special Vise Jaws.—In many cases a vise may be quickly and cheaply transformed into an efficient "fixture" by substituting special jaws for the regular jaws. Special

jaws may be shaped to the general contour to be milled, being a trifle smaller for clearance. Figure 203*a* shows a pair of vise jaws made in this way. The thin pieces, in addition to being firmly held, are "backed up" by the jaws over practically the entire surface and are thus kept from bending under the pressure of the cut.

It is unnecessary to remove the regular jaws when "false jaws," as for example *c* (Fig. 203) are used, these may be clamped between the regular jaws. False jaws are frequently used for slotting screws; they work very well even when some of the screws are a trifle small, provided the cutter is central and the screw is not too short.

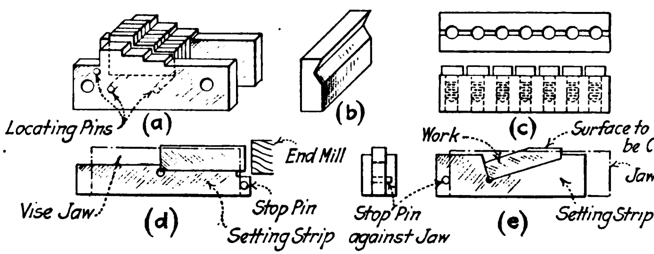


FIG. 203.—Sketches to show the use of special jaws and setting strips. (*a*) Several thin pieces in special jaws. (*b*) Special jaw for holding a cylindrical piece. (*c*) "False" jaws for slotting screws. (*d*) and (*e*) Setting strips.

Very often a setting strip in the vise may serve to accurately locate duplicate pieces. Such strips *d* and *e* (Fig. 203) may be very quickly made of a suitable piece of cold rolled steel.

GENERAL PRECAUTIONS TO BE OBSERVED WHEN SETTING UP

184. The result of vibration in any machine tool is a poor product and inefficient production; vibration dulls tools more quickly than hard work. The most important single characteristic of a first-class milling machine is its rigidity. In no other machine, excepting possibly the grinding machine, is the effect of vibration as apparent, and probably

in no machine is the expense of sharpening the cutting tools as great.

A milling machine "set-up" that would seem to permit unnecessary vibration indicates ignorance or thoughtlessness and no real machinist wishes to be classed as stupid and careless.

185. Set-up of the Work.—Have the work held as rigidly as possible and when necessary supported by a jack, or suitable packing blocks and shims. In any case, the work must be held securely and rigidly; it must not be sprung in clamping or allowed to spring under the pressure of the cut.

Have the table as close to the column as the job will permit.

While the set-up is being made, the clamping screws for both the knee and the saddle should be slightly loosened, but before starting the cut, except of course when a vertical or a lateral feed is to be used, *both clamps should be tightened.*

Milling chips are especially troublesome and the care taken to clean the seating surfaces of the work, and the clamping surfaces of the vise or table or fixture will make for speed and accuracy. *Be sure all clamping seats and surfaces are clean.*

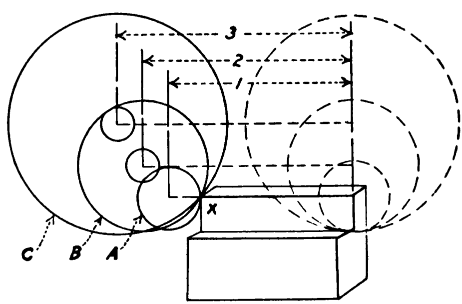


Fig. 204.

186. Selecting and Setting the Cutter.—It is frequently a waste of time to use a cutter of a diameter larger than necessary. Referring to Fig. 204, suppose that it is required to finish the surface X, the proper cutter to use is an end mill of about the diameter of A. In the figure B shows the diameter of as small a cutter as can be used and still let the arbor and collars pass over the work, while C represents a cutter of a diameter much larger than necessary. From a comparison of the feeding distances, 1, 2 and 3, it will be

observed that the cutter of smaller diameter takes less time than the cutter of the larger diameter.

Examine the cutter to make sure it is sharp.

Be sure the taper hole in the spindle is clean—free from chips and dirt, and wiped dry. Likewise the taper shank of the arbor or collet or cutter. *An oily taper will not hold*, and many jobs are spoiled by the operator neglecting this important point.

Be sure the arbor and collars and the sides of the cutter are clean.

Have the cutter as close to the spindle, and the outboard bearing as close to the cutter, as the work will permit.

To allow the arbor nut (or any nut for that matter) to tighten when only half or two-thirds on is a disgrace. Select such a collar as will allow the nut to screw on practically its full length.

187. Setting the Speed and Feed.—Among the most important considerations of any set-up are the cutting speed and feed. These must not be left to chance nor to mere guesswork. The conditions that obtain for the given job must be considered even by the experienced machinist. He usually knows what to do under the conditions. Getting this knowledge and putting it to work is *training*.

Calculate the revolutions per minute for the proper cutting speed for the given cutter and the given job; judge the amount of feed and the depth of cut according to reason. Remember the tendency to feed too slow. Remember also that in many jobs one cut is enough; two cuts (roughing and finishing) are necessary only (1) when a considerable amount of metal must be removed (2) when there is unusual tendency to spring (3) when a particularly accurate result or a particularly excellent finish is desired.

188. Setting the Feed Trip.—When several pieces are to be milled and any of the automatic feeds are used the feed-trip dog is set to operate at the desired point—usually just as the work feeds from under the cutter. If no stop for the end of the work being milled is provided on the vise jaw or other

holding or locating appliance, care must be taken, when placing the successive pieces, to place them in the same relative position otherwise the feed may stop before the cut is finished and this will produce an "undercut." In certain operations, however, the feed must be tripped during the cut and such a case requires attention, when the feed trips, to avoid an undercut.

189. Concerning an Undercut.—No matter how carefully a cutter is ground, it will not run exactly true in operation, especially a cutter mounted on an arbor. And no matter how well it may be supported there is always a certain tendency to spring under the cutting pressure. Owing to these conditions, if the feed is thrown out during the cut the cutter will mill a trifle deeper at this point. On a finishing cut this is a serious fault because an undercut only .002 or .003 in. deep is very noticeable and unless the table is raised the undercut will not be removed even if it is run under the cutter a dozen times. If necessary to stop during the finishing cut, stop the cutter and *do not* throw out the feed.

The undercut is much more pronounced if the cutter is caused suddenly to take a much heavier cut. This is illustrated in Fig. 205. When finishing such a surface (against a shoulder) the best method is to set the *automatic feed trip* to disengage the feed about $\frac{1}{16}$ in. before the heavy cut is reached, and to set the *positive stop* 46 (Fig. 140) for the end of the cut. Just before the automatic feed is tripped be ready to "catch" the feed, and feed by hand to the positive stop. It may be advisable to lower the table a little as the heavy cut is reached.

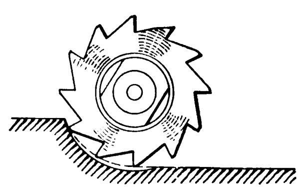


FIG. 205.—An undercut.

The same conditions that cause an undercut will tend to injure a finished surface if the work is run back under the cutter unless (1) the cutter is stopped or (2) the work is lowered a trifle. For example, suppose as the work is run back the cutter revolves four times, four "trade marks" will result because every time the cutter revolves one tooth will dig a

little into the finished surface. Setting up a milling job is considerably more than half the battle; taking the cut is comparatively simple. Know what is wanted, get ready thoughtfully and go ahead carefully. Mistakes will sometimes occur. The person who never makes a mistake never accomplishes much in this world. The mistakes of one who is attentive, thoughtful and "on the job" are excusable. The spoiled work or cutter, the delayed production, the broken machine due to the blundering stupidity of the lazy indifferent individual are results of mistakes that are inexcusable.

EXAMPLES OF PLAIN MILLING OPERATIONS

190. Milling a Rectangular Piece.—One of the simplest jobs but even so one that calls for close attention to detail is squaring up a rectangular piece as illustrated in Fig. 162. A spiral milling cutter wide enough to cover the broadest surface is used. Select parallels of the proper height so that the work does not project too far above the jaws, tighten the work securely then tap with a babbit hammer to make sure it is firmly seated. Having set the correct speed feed and depth of cut, start the cutter revolving, run the work fairly close to the cutter, then carefully till it touches the cutter, and throw in the feed. Set the feed trip dog to throw out the feed at the end of the cut. In connection with tripping the feed in milling machine work the operator must remember to so place the work as to have the end of each succeeding cut in the same relative position as the cut for which the trip was set.

Finishing a rectangular piece in the milling machine differs in no particular respect from planing a similar piece in the shaper vise or planer vise except in the machine and cutting tool used. The sequence of operations and reasons therefore and the precautions regarding chips, burrs, etc., are the same. The student is referred to the discussion of these things in paragraphs 83 and 88.

The shorter pieces may be squared on the ends with a spiral

milling cutter, when "tipped up" in the vise and one finished side squared with the bottom of the vise as explained in shaper work, paragraph 89. The vise jaws should be arranged at right angles to the direction of the cut or thework is likely to tip. If the work projects much above the vise jaws it is likely to spring and chatter, consequently most end cuts are made by laying the work flat and allowing it to project from the vise or other holding fixture and finishing with either an end mill or possibly a side mill or for the larger surfaces a face mill. If the work is long enough to project both ends beyond the holding device and there are enough pieces to warrant the set-up, a pair of side mills ("straddle mills") may be used to square both ends in one operation. In such a set-up an adjustable collar (one part screwing within the other) is very useful, but if such a collar is not available, collars of sheet copper, brass, or steel or even paper may be used to obtain the correct dimensions between the cutters. Make the trial cuts on a piece of scrap.

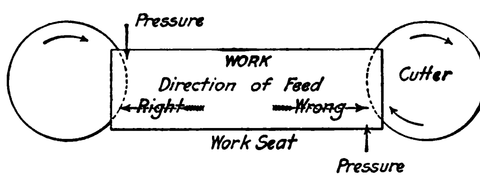


FIG. 206.

In the operation of "squaring" or "facing," the feed should be arranged if possible to have the pressure of the cut in a direction toward the seat of the work (Fig. 206) otherwise the work may be lifted from its seat and spoiled.

191. Face milling is finishing a surface at right angles to the axis of the cutter; it does not mean that the end teeth or the side teeth do the cutting. As a matter of fact the teeth on the periphery do all or nearly all of the cutting when "facing" with an end mill or a face mill or a side mill. The action of the teeth on the end (or side) when they are properly sharpened is a slight scraping or finishing cut. If these teeth are dull or improperly ground the surface produced will be rough and probably gouged here and there.

When face milling, care must be taken to have the cutter

securely in place, and also that there is no end play in the machine spindle.

If it is desired to finish a curved surface of the same radius as the cutter this may be done by feeding parallel to the axis of the cutter. In this case the end teeth do the cutting and the peripheral teeth do the finishing.

192. Cutting a Keyway or Similar Groove.—There are several different milling machine methods of cutting a keyway in a shaft, namely, with a plain milling cutter, with an end mill, with a cotter mill, with a Whitney (Woodruff system) cutter. Also there are several ways of holding the shaft—in a vise, in V-blocks, clamped to the table itself, or between the index centers or in the index head chuck. In any case care must be taken to make the keyway parallel to the axis of the shaft.

Arrange the work table and work as close to the column as practicable. The next step is to place the cutter in position. If it is a taper shank cutter place in a suitable collet and drive home, carefully, with a brass rod against the end. If a Whitney cutter (Fig. 210) is used be very sure that it is firmly held in its chuck (Spring collet see Fig. 193). If a slotting cutter mounted on an arbor is to be used place it on the arbor in approximately the correct position over the work.

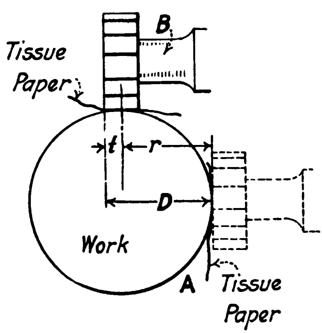


FIG. 207.—The distance *D* equals one-half the thickness of the cutter plus the radius of the work.

Assuming a cutter of the correct width is used, the work must be adjusted until the cutter is central. This is usually called "locating the cutter central" but as a matter of fact it is the work that is located.

193. Locating the Cutter Central.—One method is shown in Fig. 207. Feed the work carefully toward the revolving cutter until the cutter just tears a piece of tissue paper *A*. Then lower the table and feed in the previously calculated

distance *D*, using the graduations on the feed screw. If extreme accuracy is desired check the distance, and in any event *beware of the back lash.* If the keyway is to be cut

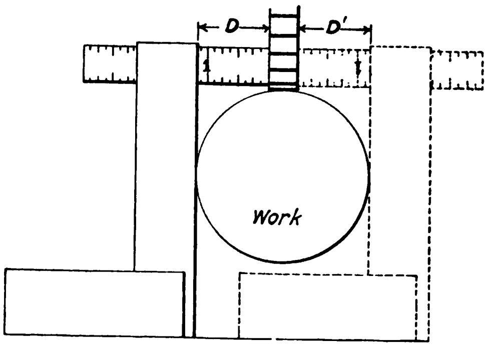


FIG. 208.—The distance *D* equals the radius of the work minus one-half the thickness of the cutter.

with an end mill or cotter mill get peripheral contact first as in *B*, Fig. 207 then adjust the work an amount equal to the radius of the work plus the radius of the cutter.

A method which may be used if side or end contact is inconvenient (as happens sometimes with a slotting cutter) is shown in Fig. 208. Place a square against the shaft and measure the calculated distance *D* or, as many prefer to do, move the work until the measurement of *D* and *D'* are equal. The cutter must *not* be revolving.

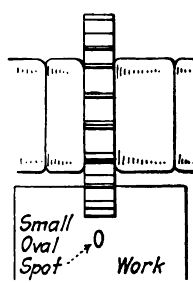


FIG. 209.—Setting the cutter central by the small oval "spot." View is looking down towards the tail stock.

Still another method that is much used and is fairly accurate is illustrated in Fig. 209. Adjust the work approximately central under the cutter and raise the table until a piece of paper is torn between the revolving cutter and the work, then raise it four or five thousandths more allowing a small "spot" to be cut. Stop the cutter, lower the table and run back a short distance. The small oval "spot" now clearly seen is exactly

over the axis of the shaft and the table must be adjusted until the spot appears midway between the sides of the cutter.[1]

194. Adjusting for Depth of Cut.—When it is desired to make a cut a certain depth (or at a certain distance from a given surface) the work is carefully fed by hand in the necessary direction until a piece of paper held against the given surface is torn by the revolving cutter. (*Use a long piece of paper; keep your fingers away from the revolving cutter.*) This is the starting point for the final adjustment and it is a good plan to set the graduated collar at zero. Then move the work the distance required. The contact position when setting up for cutting the keyway, Fig. 207 is shown at *B*.[2]

It makes no particular difference whether the base surface (surface to be gauged from) is curved or flat, vertical or horizontal, the above suggestions will apply.

195. "Whitney" Keys.—A line of keys of standard size with cutters to correspond which has deservedly found much favor in machine construction is known as the "Whitney" (Woodruff patent).

The keys *a* (Fig. 210) are denoted by number or letter, as the case may be, and the corresponding cutter *b* will cut a groove into which the key will fit properly. Frequently a series of two or more keys are used as shown in *d*.

Cutters are furnished either right hand or left hand as desired. For sizes of cutters and keys see Table 7, page 405.

When setting up, adjust the machine table crosswise until the cutter is central over the shaft *c* (Fig. 210). Scribe a

[1] In a test conducted with a class of ten boys the greatest error made was .003 in.

[2] It should be remembered that the depth of keyways and similar grooves is measured from the edge of the slot and consequently the work must be raised a certain amount after it touches the cutter before beginning to cut the proscribed depth of the keyway. Table 8 gives the various amounts to raise the work for sizes of shafts up to 2¼ in. diameter. For larger sizes consult "American Machinist's Hand Book." For ordinary work, scale measurement from the edge of the keyway is satisfactory.

line (on the first piece) indicating the middle of the key position *d*, and run the work under the cutter until the line is under the axis of the cutter. Then raise the table to cut the groove to the correct depth, using plenty of cutting compound. It is customary to cut the key seat to such a depth that the key will project one half its thickness above the shaft. When the correct position of cutter and depth of cut has been determined set the graduations at zero; if a hand milling machine is used, set the positive stops.

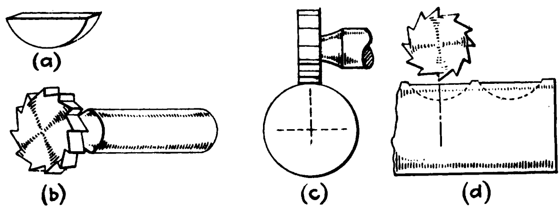


Fig. 210.—(*a*) Whitney key; (*b*) cutter; (*c*) end view of set up; (*d*) side view of set up.

Succeeding pieces should be located lengthwise by a suitable stop or otherwise to bring the key in the same relative position on each piece.

Questions on Milling a Plane Surface

Carefully clean the milling machine table and the base surface of the vise. Clamp the vise securely to the table and arrange the work in the vise for milling. Move the table as near as practicable to the column of the machine. Select a spiral milling cutter and the arbor to be used, wipe the taper hole in the spindle and the shank of the arbor clean and arrange the arbor in the spindle.

1. What is a plain milling cutter used for?

2. What is the advantage of the spiral tooth?

3. How much clearance is given the cutting edges of these cutters? Why not more? Why not less?

4. Why is it best to have the table as near the column as possible?

5. What is the proper position on the arbor of the outboard bearing collar? Why?

6. What kind and size of cutter did you select for this job? Why?

7. Why do you have the tapers clean and dry?

8. How do you properly arrange the arbor in the spindle?

9. How far should the nut screw on the end of the arbor? Why?

10. What difference does it make whether the thread on the arbor is R. H. or L. H.?

11. What direction does the cutter revolve? In what direction does the table feed? Why?

12. What number of revolutions per minute is necessary for the cutter to revolve on this job? Why?

13. How much feed will you use for this job? Why? What are some of the conditions that govern the amount of feed?

14. Do you need parallels on this job? Give reason.

15. How do you seat the work in the vise?

16. When do you use cutting lubricants in milling machine work?

17. What is the effect if care is not taken to clean away the chips before putting work in the vise (*a*) on the work? (*b*) on the parallels? (*c*) on the vise?

18. What will be the effect of dirt or chips between the arbor collars?

19. Why should not the revolving cutter be run back over the work?

20. What causes vibration? What are some of the ill effects of vibration?

21. What is the effect of using a dull cutter (*a*) on the work? (*b*) on the cutter?

22. What is considered a safe cutting speed with a carbon-steel cutter for (1) cast iron, (2) machine steel, (3) tool steel? With a high-speed cutter?

23. What is the characteristic of high-speed steel that makes it valuable for a milling cutter.

24. If the surface to be milled is narrower than half the length of the cutter, what part of the cutter will you set up to use? Why?

25. It is fairly impossible to have a cutter run exactly true. Sometimes on the smaller cutters where a key is not necessary, the cutter may be given part of a turn and cut better. Why?

Questions on Milling a Rectangular Piece

Rectangular pieces to be milled are usually held in a vise. Clamp the vise in position on the milling machine table and obtain from the toolroom the cutter and other tools required. Proceed to set up the job to take the first cut.

1. What kind of vise is most convenient and adaptable for this job? Why?

2. Name and describe three kinds of vises used in milling machine work.

3. How will you set the vise jaws square with the axis of the cutter?

4. Of what value is the key in the base surface of the plain vise? Why are there two keyways at right angles to each other?

5. How would you set the plain vise with jaws at an angle of 45° with the axis of the cutter?

6. Explain in detail the correct method of setting up this job—the position of the vise, the position of the table with reference to the column, the selection and setting of the arbor, the placing of the cutter and the out-board bearing collar.

7. How will you set the piece in the vise? Are protecting pieces necessary? Give reason.

8. If parallels are necessary, how are they arranged? What size of parallels is advisable? Why?

9. Why do you mill one of the larger surfaces first?

10. What number of revolutions per minute is necessary to give the required cutting speed?

11. What feed is advisable? Why?

12. Will a roughing and finishing cut be necessary? If it is advisable to take a second cut will you rough the piece all over before taking the finish chip on any surface? Give reason.

13. Will you use a cutting lubricant? Give reason.

14. After the first surface has been milled which is the next surface to cut? Why?

15. What is the purpose of using a narrow strip or a rod between the movable jaw and the work?

16. Which is the third surface? Why? Is the strip or rod necessary? Why?

17. How do the graduations on the screw help in obtaining the proper size?

18. If only two opposite surfaces were to be milled how would you hold the work when milling the second surface?

19. State two ways of holding a rectangular piece to mill the end square.

20. If a short piece is held in one end of the vise, why is it advisable to use a spacing block of equal thickness in the other end?

21. What is meant by a plain vise?

22. Explain the advantage of a swivel vise. Why is it not as sturdy as a plain vise?

23. What features of the universal vise make it possible to take cuts at any angle in both vertical and horizontal planes?

Questions on Face Milling

Get an angle iron and fasten it by means of either bolts or clamps to the table of the milling machine. Do not fasten it too tight until it is exactly square. Proceed to square the face of the angle iron by the most practicable method.

1. If a square is used, against what part of the machine is the beam of the square held? Why? Could it be held against the side of the table?

2. How are pieces of tissue paper used as "feelers?"

3. What is an indicator? With how many kinds of commercially made indicators are you familiar?

4. How is the indicator held between the arbor collars? How do you keep the arbor from moving?

5. When is the piece square by the indicator reading?

6. Can you explain how the graduations of the feed screw may be used for setting the angle iron square?

7. Can these methods of setting an angle iron square be used for setting a vise, or a strip, or a finished face of the work square?

8. If a universal milling machine is used how do you use parallels between the table and the finished face of the column to align the table?

9. What do you understand by the term "face milling?"

10. How does the finish compare with the plain milling cutter finish?

11. What will cause a corrugated surface?

12. What will cause a scratched surface?

13. How many degrees clearance has a milling cutter tooth?

14. Why must extreme care be taken that there is no excessive end play in the spindle bearing?

15. Why should not the cutter be run back over the finished surface?

16. When a number of pieces are being faced, why should the work be tested frequently? When is the best time to test the piece?

17. What is the value of a "stop" against the work?

18. Why is it unnecessary in face milling to feed the work until it is entirely beyond the cutter? When is the cut finished?

19. Why in face milling is it often advisable to remove the work before running the table back?

Questions on Cutting Keyways, Grooves, Etc.

1. If a piece of paper is held between the work and the cutter and the work table is moved until the revolving cutter just touches the paper, how near is the work to the cutter? Why is this method better than to attempt to just touch the work?

2. Can the work be brought to the side of the slotting cutter, for example, in the same way?

3. Why must you be extremely careful of your hands when working near a milling cutter?

4. Suppose a shaft 1½ in. in diameter is to have a keyway ⅜ in. wide. When the side of the cutter just touches the side of the work how far should the table be moved to bring the same side of the cutter to the correct position to cut the side of the keyway? Why not ¾ in.?

5. How is the shaft clamped to the table? Under what conditions is this a proper method?

6. When may V-blocks be used advantageously?

7. When may the index centers be most efficient?

8. What conditions would determine whether the shaft should be held on centers or in the chuck?

9. Of what value is the center rest or jack?

10. Where is the depth of a keyway measured? How usually?

11. What is the reason you cannot use an end mill as a drill?

12. What advantage has an end mill with center cut?

13. What kinds of cutters may be used for cutting keyways?

14. What is the chief advantage of a cotter-mill?

15. Are you able to file the end of a piece of drill rod to the form of a cotter-mill and produce the correct shape of end teeth and all clearance angles?

16. What are the differences between the end mill and the cotter-mill as regards speed, feed and chip?

17. If a plain milling cutter of the correct thickness is used, why is the smallest diameter that may be used the best?

18. What determines the smallest diameter of cutter that may be used?

19. What would you do if a cutter of the correct thickness was not available?

20. What is the chief fault of a keyway cut with a plain milling cutter?

21. What are some of the advantages of the Whitney (Woodruff) system of keyway cutters and keys?

22. How many sizes of Whitney (Woodruff) keys are listed as standard?

CHAPTER XII

THE INDEX HEAD AND INDEXING OPERATIONS

196. Introduction.—Indexing may be defined as the process of causing the work to be moved any desired definite amount on its axis, as for example, the distance from tooth space to tooth space when cutting a gear or from groove to groove when fluting a reamer or a milling cutter. This is accomplished by means of a mechanism contained in the attachment called the index head. The index head, sometimes called "dividing head" or "spiral head," constitutes the chief factor in the wonderful development of the milling machine into one of the most important of machine shop tools.

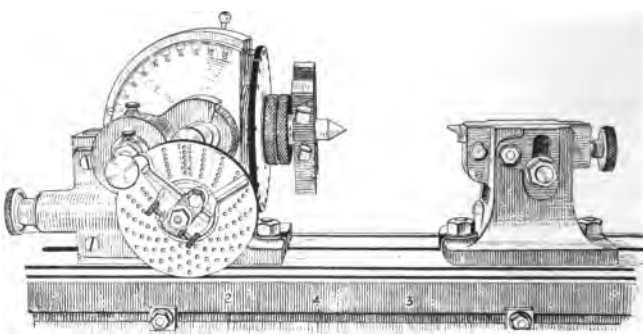


Fig. 211.—Brown & Sharpe index centers. Head on left end of work table.

The index head, together with its foot stock, are known as the index centers. The practice of several manufacturers is to arrange the index centers on the milling machine table with the head at the left (Fig. 211), other manufacturers reverse this arrangement (Fig. 212).

197. The Index Head.—The index head (Figs. 213 and 214) contains the work spindle and the mechanism (worm and wormwheel, explained in paragraph 199) for obtaining a rotary movement of the spindle when required. *The work spindle* is

provided with a taper hole to receive the live center or the taper shank of other tools, and with a threaded end or "nose" to hold a chuck or any special work-holding device. The

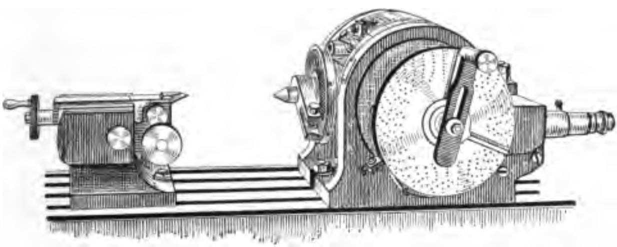


FIG. 212.—Cincinnati index centers. Head on right hand end of work table.

spindle has a large bearing surface accurately fitted, and in addition, a clamping device to give greater accuracy and rigidity under a heavy cut. The spindle is carried in the *swivelling block* which is arranged between housings cast

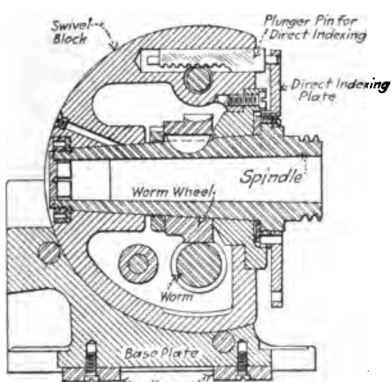


FIG. 213.—Vertical section (Brown and Sharpe) index head.

integral with the base plate. The swiveling block is so constructed that it may be tilted until the spindle is in any desired position from 5° below the horizontal to at least 10° beyond the perpendicular and then clamped rigidly to the

base casting (see Fig. 169A). Graduations in half degrees show the angular position. The base is provided with keys which fit the slots in the work table.

Descriptions of other parts of the index head are given further on in connection with discussions of the mechanisms.

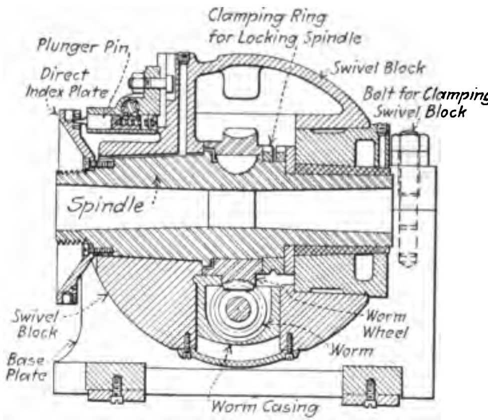


FIG. 214.—Vertical section Cincinnati index head.

198. The footstock is used for supporting the outer end of pieces being milled. Primarily it is for work held on centers but may be used if necessary for work held in a chuck or otherwise. The footstock center may be adjusted longitudinally and in addition the block which holds the center and its adjusting screw may be moved vertically and may also be tilted out of parallel with the base to line with the index head center when it is tilted for the purpose of milling tapered work.

The primary purpose of the mechanism of the head is indexing.[1] There are three different methods of indexing: Simple, direct, and differential.[2] The first two are chiefly used.

[1] For description of the auxiliary gears, etc., which makes the difference between the "spiral head" and the index head, (see paragraph 214, p. 276).

[2] For description of differential indexing, see "Treatise on Milling Machines," published by Brown & Sharpe Manufacturing Co. and BURNHAM'S "Mathematics for Machinsts," published by John Wiley & Sons.

199. Simple Indexing.—Simple indexing is accomplished by means of a mechanism (Fig. 215) which consists essentially of a 40-tooth wormwheel fastened to the work spindle, a single cut worm, a crank for turning the wormshaft, and an index plate. Since there are 40 teeth in the wormwheel one turn of the index crank will cause the wormwheel to make $1/40$ of a turn, or in other words, 40 turns of the index crank revolves the spindle one full turn. Suppose it is required to cut a reamer with 8 equally spaced teeth: if 40 turns of the index

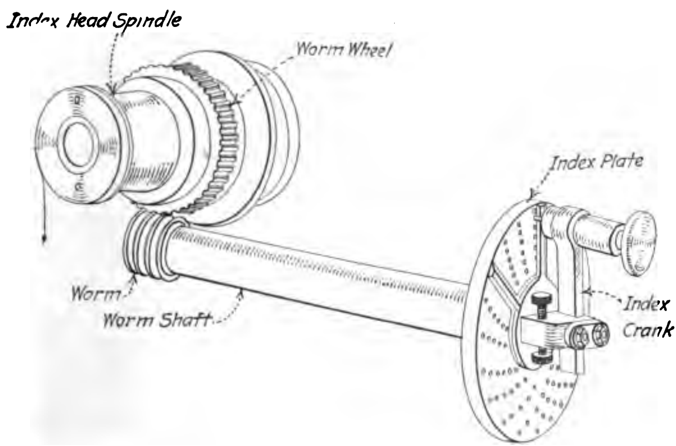


FIG. 215.—Simpler indexing mechanism.

crank make one full revolution of the work, then $1/8$ of 40 turns or 5 turns after each cut will space the reamer for 8 teeth. If it is required to space equally for 10 cuts, $1/10$ of 40 turns or 4 turns will give the desired result.

Note, in the examples given, that 40 divided by 8 equals 5 turns and 40 divided by 10 equals 4 turns. As a further example, let it be required to index for 6 equal spaces, then 40 divided by 6 equals $6\frac{2}{3}$ turns, or again, 14 equal spaces are required, then 40 divided by 14 equals $2\frac{6}{7}$ turns.

These examples may be multiplied almost indefinitely and from them may be deduced the following:

Rule for Calculating Turns of Index Crank.—To obtain the number of turns (whole or fractional) of the index crank for one division of any desired number of equal divisions on the work, divide the number of turns for one full revolution of the spindle (usually 40) by the number of equal divisions desired, or $\frac{40}{D} = T$.

200. Index Plate and Sector.—The fractional parts of a turn involve the use of an index plate and sector. Referring to Fig. 215, it will be observed that the index pin at the end of the index handle enters a hole in the index plate. If only

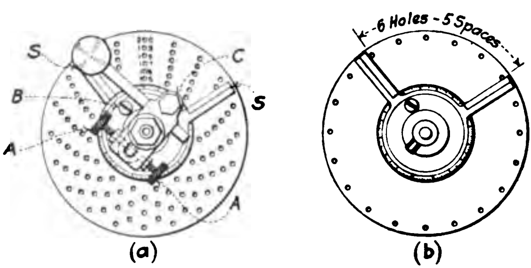


FIG. 216.—Index plate and sector.

full turns were used in indexing, one hole only would be necessary, if only turns and half turns were required two holes in opposite sides of the plate would answer, but a great number of different fractional parts of a turn are required for different spacings, and in order to accurately and easily measure them, the index plates and the sector are provided.

The index plate (Fig. 216) is a circular plate, arranged in front of the index handle, provided with a series of six or more circles of equally spaced holes.[1]

[1] The Brown & Sharpe Manufacturing Co. regularly furnish index plates with circles of holes as follows:

Plate 1	15–16–17–18–19–20
Plate 2	21–23–27–29–31–33
Plate 3	37–39–41–43–47–49

For divisions which cannot be obtained with any of these circles differential indexing is used.

With the index plates regularly furnished it is possible to obtain the spacings ordinarily used for gears, clutches, milling cutters, etc. Two examples will illustrate.

First Example.—To mill a hexagon.

Solution.—Using the rule: $^{40}/_{6} = 6^{2}/_{3}$ turns, or six full turns and two-thirds of a turn on any circle divisible by 3, for instance, 12 spaces on the 18 circle or 26 spaces on the 39 circle.

Second Example.—To cut a gear of 42 teeth.

Solution.—$^{40}/_{42}$ or $^{20}/_{21}$ turns, that is, 40 spaces on the 42 circle (Cincinnati) or 20 spaces on the 21 circle (Brown & Sharpe).

Referring to Fig. 216, the index crank is adjustable radially (first loosen screw *C*), so that the index pin may be used in any of the circles of holes in the plate. The index pin is held in the hole by a spring contained in the handle and when the pin is pulled against the force of the spring, out of the hole, the crank may be moved.

The *sector* (Fig. 216) consists of two radial arms *S*, so constructed that the angle included between them may be changed (first loosening the binding screw *B*). The use of the sector obviates the necessity of counting the holes, at each cut, for the fractional part of a turn, and in addition to saving time makes for accuracy. Select a circle divisible by the denominator of the required fraction of a turn (reduced to lowest

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The Cincinnati Milling Machine Co. regularly furnish one plate drilled on both sides which has circles of holes as follows:

First side——24–25–28–30–34–37–38–39–41–42–43
Second side—46–47–49–51–53–54–57–58–59–62–66

This company furnishes as an "attachment," three plates drilled on both sides with holes as follows:

Plate	*A*	30–48–69–91– 99–117–129–147–171–177–189
	B	36–67–81–97–111–127–141–157–169–183–199
Plate	*C*	34–46–79–93–109–123–139–153–167–181–197
	D	32–44–77–89–107–121–137–151–163–179–193
Plate	*E*	26–42–73–87–103–119–133–149–161–175–191
	F	28–38–71–83–101–113–131–143–159–173–187

terms) and bring the beveled edges of the arms of the sector to include the fractional part of the circle desired. In counting the holes in the plate when adjusting the sector *remember it is really the number of spaces between the holes that gives the desired fractional part of the whole circle.* Consider the hole the pin is in as zero. An example is illustrated in *b*, Fig. 216.

When the spindle is not clamped, the index handle should turn easily.

The sector is under spring tension in order that it will remain set. It should however be easy to move to the next setting. Move the sector *immediately* after indexing, then it will always be in position for the next indexing operation.

The number of spaces on the index circle indicating the fractional part of a turn should be included between the *bevelled* edges of the sector arms.

Form the habit of turning the *index handle to the right*, to avoid confusion. Stop between the last two holes and gently rapping the handle allow the pin to snap into place. If the handle is turned too far, turn back far enough to *take up the lost motion* before allowing the pin to snap into place.

Sometimes after the work has been exactly adjusted, to a cut already made for example, the index pin will come between two holes in the plate, and a means for allowing the pin to enter the nearest hole *without changing the position of the work* is provided. In the Brown & Sharpe machine the screws *A* (Fig. 216) are used for this purpose and in the Cincinnati machine, the index plate lock is loosened and the plate moved until one of the holes comes to the pin.

The worm and wormwheel and the spindle are so arranged within the swivel block as to permit of indexing in any position within the angular range and this feature of the head is used for cutting clutches, bevel gears, end teeth on cutters and many other jobs.

201. Indexing in Degrees.—There are 360° in a circle and one turn of the index handle will revolve a point on the circumference of the work $\frac{1}{40}$ of a circle or 9°. Consequently one-ninth of a turn (2 spaces 18 circle—3 spaces 27 circle—

6 spaces 54 circle) equals 1°. Further the work may be indexed $\frac{1}{2}$° (1 hole 18 circle) or $\frac{1}{3}$° (1 hole 27 circle) and of course 2°, 3°, etc., provided a circle divisible by 9 is used. For smaller divisions than $\frac{1}{3}$° on the Brown & Sharpe machine, differential indexing is used and for smaller divisions than $\frac{1}{6}$° on the Cincinnati one of the three extra plates may be used. In either case it may be well to figure the number of divisions required; for example, to index for $\frac{1}{4}$° use four times 360 divisions or 1440 divisions $\frac{40}{1440} = \frac{1}{36}$ of a turn.

202. Direct Indexing.—The construction of the universal index head permits of disengaging the worm from the worm-wheel. The object of throwing the worm out of mesh with the

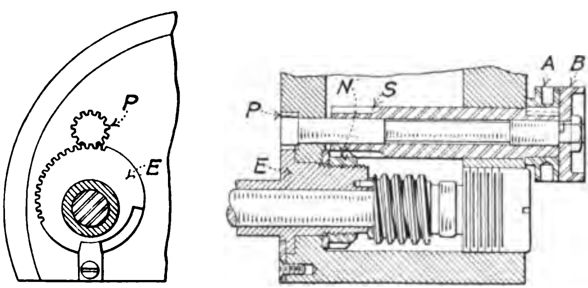


FIG. 217.—Portion of *horizontal* section Brown and Sharpe index head.

To lower the worm out of mesh with the worm wheel, first disengage stop pin from index plate, then turn knob A about one-quarter revolution in the *reverse* direction to that indicated by the arrow on A. This will loosen nut N which clamps eccentric bushing E (Note: the sleeve S and the nut N are provided with gear teeth). After N is loosened, turn both knobs A and B; this will turn the pinion P and revolve the eccentric bushing E which lowers the worm.

wormwheel is to make possible a very much quicker method of indexing, called direct indexing, for the more commonly used divisions. Disengaging the worm from the wormwheel is accomplished by turning through part of a revolution a knob or handle that operates an eccentric (see Figs. 217 and 218). In many designs of index heads, for example in in the Brown & Sharpe, the *stop pin* must be out of the index plate *before the worm is lowered.*

Direct indexing (sometimes called quick indexing) is accomplished, after the worm is lowered, by means of a plate with at least 24 equally spaced holes, which is fastened to the front of the work spindle, and a plunger pin which is located in the head and fits the holes in the plate (see Figs. 213 and 214). The plunger pin holds the plate in position. When the plate is turned by hand the required part of a revolution, the index-spindle and the work also turn that same part of a revolution. Direct indexing is used to advantage when milling squares or hexagons, fluting taps, counterbores, etc. Any number of divisions which is a factor of 24 may be quickly indexed; as, 2, 3, 4, 6, 8, 12, 24.

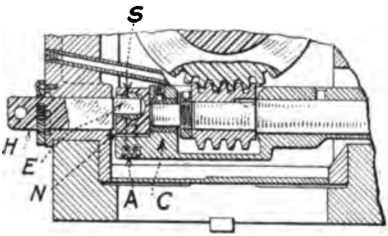


FIG. 218.—Portion of *vertical* section of Cincinnati index head.

The worm is lowered out of mesh with the worm wheel by moving the handle *H* one-half turn. This operates eccentric *E* which is journaled crosswise in the cylindrical sliding piece *S* carried in the holder *N*. The worm carrier *C* is fastened to *N* (by two screws *A*) consequently when the slide holder *N* is raised or lowered the worm casing and worm are raised or lowered.

Questions on the Index Head and Indexing

1. The work spindle is turned by an enclosed worm and wormwheel. In certain other machines, possibly on the drill press, the action of the worm and wormwheel may be seen. Find an example.

2. How can you determine the number of teeth on the wormwheel in the dividing head?

3. How many turns are necessary to index for a gear of 20 teeth? For 40 teeth? For 80 teeth?

4. State a rule for determining the number of turns or the fractional part of a turn of the index handle to be made for any given number of divisions.

5. How many circles of holes has the index plate that is on the head? How many of these circles are divisible by three? How would you obtain two-thirds of a turn?

6. Are there any index plates other than the one on the head furnished with this machine?

7. How may the index crank be adjusted radially to permit the pin to enter a hole in the desired circle?

8. What do you use to save counting the holes for every move? How are the arms adjusted and set to include the desired number of holes?

9. If two-thirds of a turn is required and an 18-hole circle is used, what number of *holes* is included between the arms of the sector? Why not 12?

10. What part of a turn will you make to cut a gear of 42 teeth? What circle will you use? How many holes will be included between the arms of the sector?

11. In which direction should the index crank be turned? Why?

12. What keeps the index plate from turning when the crank is turned?

13. Tip the head to a vertical position. Can indexing be accomplished? Tip the head to 45°. Are you able to index in this position?

14. In some makes of index heads a plate with 24 divisions is fastened to the spindle just back of the driver. What is the use of this plate?

15. How may the worm be disengaged from the wormwheel? When is this necessary? Why?

16. Before disengaging the worm why is it necessary to take out the stop-pin? Why is it unnecessary to take out the index-pin?

17. What advantage has direct indexing? Why are there 24 holes in the direct index plate? How are these holes numbered?

18. Rearrange the dividing head for simple indexing. How do you know when the worm properly engages the wormwheel?

19. Obtain a rod (brass is best) about ¾″ diameter, 6″ or 7″ long and knock out the index head center. When is the center removed from the dividing head spindle?

20. What standard taper has the spindle hole?

21. Why is a guard screwed on the nose of the spindle when the center is being used?

22. How is a chuck mounted on the index head spindle?

23. What block is needed in order to set the dividing head at any other angle than parallel with the table? How do you set this block square? How do you set it at any other angle?

24. How do the tailstock of a lathe and the footstock of a milling machine compare in purpose?

25. What adjustment does the footstock have that the tailstock does not have?

26. What adjustment does the tailstock have that the footstock does not have?

27. Frequently one or more square or hex. head taper pins are used to locate and "anchor" a movable part in its normal position. Are you able to find such a feature in the footstock?

TYPICAL INDEXING OPERATIONS

203. Milling a Square or a Hexagon.—When milling a "square" or a "hex" on a bolt or any piece that requires a similar operation it may be necessary to hold the work between centers, or perhaps in a chuck and supported by the footstock center, and take a vertical cut (Fig. 219). It is advisable however, when practicable, to knock out the index head center,[1] tip the head spindle to a vertical position, take off the nose guard which protects the thread on the end of the

FIG. 219.—Milling square on a long reamer. FIG. 220.—Straddle milling.

spindle, screw the chuck on the spindle and hold the work vertically in the chuck (Fig. 220). A protecting piece of brass or copper may be needed between the chuck jaws and the work. To keep the chips that may fall in the hole from becoming lodged between the swivelling block and the base plate and possibly (later when the swivelling block is moved),

[1] A piece of brass rod about ¾ in. diameter 6 in. or 8 in. long is very useful for knocking out the center, driving home the collet or the end mill, or the arbor if no draw-in bolt is provided.

scoring one or the other, a cap is provided that fits in the small end of the spindle hole. If the cap is not at hand, stuff a small quantity of waste in the hole.

Using this method (holding the work vertically) the regular table feed may be used and the cutting action more easily observed. Further if a number of pieces are to be milled, straddle mills may be used. If only one cutter is used a suitable end mill is selected and the direction of the cutter and the feed should be arranged to tend to screw the chuck on rather than to unscrew it.

Using an End Mill.—Such jobs as squares, hexagons, etc., are measured "across the flats." Assume a cylindrically turned head of a tool post screw for example is to be milled square using an end mill. The amount of stock to be removed from each side will equal one-half the difference between the diameter of the turned head and the distance across the flats when finished milled. This amount may probably be removed in one cut, but when milling the first piece it is best to take two opposite roughing cuts, measure across, subtract from this measurement the finished dimension, and move the work in one-half the difference. Direct indexing may be used in this class of work to save time.

Using Straddle Mills.—When any considerable number of pieces are to be milled it will be advisable to straddle mill them. Obtain a pair of side milling cutters of the same diameter, of such a size that the collar between them when arranged on the arbor will clear the top of the work, but not unnecessarily large. Clean the hole in the spindle also the shank of the arbor and *be sure the arbor is firmly held.* Leave enough collars on the arbor to bring the first cutter in about its proper position with reference to the work when the work table is fairly close to the column. Select a collar (possibly two or more) that will fill the space between the *hubs* of the cutters when the *cutting edges* are the right distance apart. It may be necessary to use two or three "spacers" made of paper or some thin metal.

Put on the other collars and the nut, having the bearing

collar so placed on the arbor as to bring the outer arbor support as close to the cutters as the work (and chuck) will permit.

It is now necessary, first, to make sure that the cutters are correctly spaced and, second, that the work is correctly positioned laterally. It will be best in order not to injure or possibly spoil one of the pieces to be milled to get a piece of scrap of approximately the size of the work and catch it in the chuck. Feed the table by hand laterally until the work appears central, and vertically until a cut $\frac{1}{8}''$ or more deep may be made across the top of the scrap piece. Start the machine and feed into the piece far enough to be able to get a measurement across the flats and by so doing find if more or less space is advisable between the cutters. Add or take away spacers as needed to give the accuracy required and take another cut to check the result. It may be necessary for the beginner to make three or four changes before he gets the right thickness.

After making the cut of the right thickness across the piece run the work back and index half way around. If the work will now pass between the cutters without either cutter taking a chip it is central. If it is not central one cutter will remove metal and reduce the thickness of the head a certain amount, the other cutter will be a like distance away from the surface. To correct the setting, measure the thickness as now cut and subtract it from the thickness previously cut and feed the work one-half this difference away from the cutter that took the chip. It will be advisable to check this setting to insure accuracy after which the work to be milled may be placed in the chuck and the table adjusted vertically until the correct depth of cut is obtained. Make sure that each succeeding piece projects from the chuck the same distance in order to maintain uniformity; possibly a freely fitting collar under the head of the bolt or screw being milled will be an advantage.

Questions on Milling a Square or a Hexagon

1. What care must be taken when putting the chuck on any machine spindle?

2. How is the index head center removed?

3. For what purpose is the cap in the end of the hole?

4. How are the swivelling block bearings oiled? How often?

5. If only a few bolts are to be squared, why is an end mill the best cutter to use?

6. When setting-up, rough one side of the bolt head then the opposite side, measure across and move the work toward the cutter one-half the amount of the oversize. Why is this the correct method of procedure? Is this correct when the work is held horizontally instead of vertically?

7. Would the vertical feed or longitudinal feed be used to mill the square on the end of a reamer held between centers? Why? What feed is used when the work is held vertically? Give reason?

8. If a considerable number of bolts are to be squared why is straddle milling the better method?

9. Lay the edge of a scale across the face of the side mill, and look under it. Have the side teeth any other clearance than the land clearance? Give reason.

10. Is the length of the hub equal to the width of the face of the cutter?

11. If it is desired to use a pair of these side mills for straddle milling will a collar the same thickness as the width of the cut be used? What thickness will be used?

12. Why are the collars for milling arbors furnished in various thicknesses or lengths?

13. Why are spacers of thin metal valuable when using straddle mills? Could paper be used?

14. Do the side teeth of a side mill cut when straddle milling? Of what use are they?

15. Why is it advisable to slightly round the corners of side mills with an oil-stone?

16. What would be the value of a small collar under the head of the screw or bolt being milled?

17. How many turns of the index handle are necessary to mill a hex bolt head? What circle do you use? How many holes? How many holes are included between the arms of the sector?

18. How would you proceed to obtain the correct size across the flats when using a pair of straddle mills?

19. How would you proceed to make sure the head is central?

20. Could the outside face of the outside straddle mill be used as suggested in Question 6 to obtain a head of the right size and central?

204. To Cut a Spur Gear. 28 Teeth. 10 Pitch.—For typical set-up see Fig. 154.

1. Obtain from the tool-room or elsewhere a 10 pitch gear cutter No. 5, a mandrel to fit the gear blank, a suitable arbor for cutter, a dog, etc.

2. Oil the mandrel, press it in the gear blank *tight* and put on the dog.

3. Be sure the index centers are in line (horizontally).

4. For indexing 24 teeth, $40 \div 24 = 1\frac{16}{40} = 1\frac{2}{5}$ turns of index handle. Arrange the index pin in any circle divisible by 5 and set the sector to include two-fifths of the number of spaces. Be sure the index handle turns freely and that the sector moves easily enough.

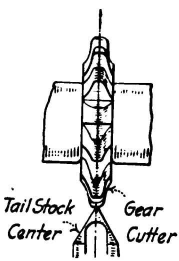


Fig. 221.

5. Run the table in practically to the column for sake of rigidity.

6. Arrange the cutter arbor in the spindle and arrange the cutter on the arbor in a position substantially over the center line of the index centers.

7. Raise the table if necessary and run the dead center nearly to the cutter and adjust until it appears central as in Fig. 221. This is probably near enough.[1]

[1] To set a cutter exactly central, for example, a gear cutter or similar cutter, it is best to use a trial blank. This trial blank may be of any convenient size and should be mounted in the usual way as near central with the cutter as possible. Take one cut through the blank, then removing the dog turn the work end for end and replace between centers without the dog. Apply blue vitriol to sides of the groove already cut and feed the cutter into the groove a sixteenth or an eighth of an inch. One or two revolutions of the cutter is all that is necessary. If it is out of central the appearance of the surface of the groove will indicate clearly that the cutter is removing stock from the top of one side and from the bottom of the other side.

In case the cutter is not central, the work should be moved laterally in the direction away from the side of the groove from which the stock was removed on the top, and another groove cut and the above operation repeated until the cut is central.

If the cutter is exactly central, the outline of the second cut will coincide with the first and a slight but even amount of the blue vitriol will be removed from the surface of the groove under the cutter.

8. Lower the table and arrange the work between centers, *lightly* clamping the tail of the dog in the carrier slot. Do not tighten the clamping screw too much or the dog and consequently the work will be cramped.

9. Run the work under the cutter and raise the work table until paper is torn between the revolving cutter and the blank, then .001 in. or .002 in. more until the cutter just touches the work.

10. Set the graduated collar on the vertical feed at zero.

11. Run the work from under the cutter and raise the table to position for the roughing (stocking) cut. Full depth of tooth space (10 pitch gear) is .216 in.; roughing cut about .180 in. to .190 in.

12. Rough one tooth—and set the automatic feed trip.

13. Run the table back to starting position. *Always be sure to run it back far enough.*

14. Index $1\frac{2}{5}$ turns for the next tooth, and so on until all teeth are roughed.

15. Raise the table to .216 in. (full depth of cut) and take the finishing cut for each tooth. When finishing, stop the cutter before running back (see paragraph 175, p. 221).

205. Fluting Reamers, Taps, Etc.—Standard cutting tools like drills, milling cutters, reamers, taps, counterbores, etc., can be purchased in the open market much cheaper than they can be made in the average shop because the manufacturers of these tools have special facilities for quantity and quality production. Since *special* tools are expensive anyway and very often the delay incident to having them made outside makes this course prohibitive, it may be economical and often necessary to make them, especially reamers, taps, and cutters. This means that the resourceful machinist is able to turn, mill, harden, temper, and grind these tools.

Reamers and taps are cut with special cutters (Fig. 182). The operations incident to setting up the machine and taking the cut are substantially alike. The number of teeth and the width of the land depend upon the size and purpose of the given tool. If a drawing is not furnished possibly a standard tap or reamer of about the size called for is available for use as

a model. Tables of sizes of all such tools are given in "American Machinists' Handbook."

It will be remembered that the function of a reamer is to *finish* a hole round and smooth. Any tendency to dig in and to chatter will defeat this purpose. If the reamer teeth have rake, the tendency is to hook into the surface and produce a hole oversize in spots and probably rough. Therefore, the teeth should be radial or possibly a trifle ahead of center (negative rake). If the teeth are given too much clearance the tendency to wobble and chatter is greatly increased. Therefore, after the reamer is ground to size, or half a thousandth over size, it may be sufficiently backed off in a short time with a suitable carborundum or India oil-stone. If the teeth of a reamer are equally spaced the tendency is for each tooth to cut a trifle deeper than the preceding tooth which produces a hole with a wavy surface—as many waves as there are teeth. Consequently, reamers are usually made with unequally spaced teeth (paragraph 206).

A double angle cutter is best for fluting reamers, taps, end mills, etc., for the reason that both sides of the groove are then clean cut, that is, no part of the surface of the groove is scored by dragging of teeth or chips. To cut a groove with one side radial when using a double angle cutter, it is of course necessary to off-set the work laterally. The amount of off-set depends on the number of teeth and the width of the land between the teeth and also on the shape of the cutter.

The "cut and try" method is used. The beginner will find it rather difficult to set the cutter so that when the face of the tooth being milled is radial the land is of the required width, and it will be advisable for the first job at least to turn up a trial blank the diameter of the given reamer or tap.

Apply blue vitriol solution on the end of the blank and using a center square and a sharp scriber, draw a radial line. Placing the blank between centers, line up the shorter edge of the cutter with this line as shown in Fig. 222 for the trial cut. (It is better to have the trial cut *somewhat less* than the proper depth.) Cut a short distance in the first groove, run back,

index to the next groove, and cut a short distance in that. Note if the cutter splits the line, and note also the width of the land. Assume the line is split, giving a radial face to the tooth but that the land is too wide. In this case it will be necessary to cut deeper and also to feed the table laterally to move the line away from the cutter so that when the work is raised for the deeper cut, the face will remain radial. When these lateral and vertical adjustments are made, re-cut both grooves and note as before the radial line and the land. To check the set up, stop the machine, remove the blank, and placing a scale against the cutting edge, see if it is in alignment with center as in *b*, Fig. 222. When the setting is correct substitute the reamer for the trial piece. Remember that the cutter does not cut its full depth until its axis is over the end of the piece (*A*, Fig. 223). Remember also to set the automatic feed trip to operate when the axis of the cutter is directly over the shoulder of the tap or reamer as shown (*B*, Fig. 223).

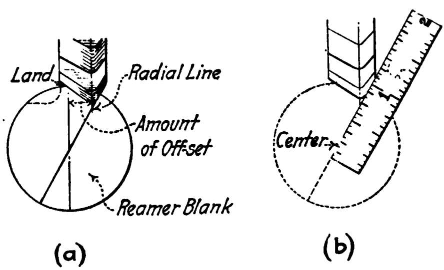


FIG. 222.—(*a*) Setting reamer cutter. (*b*) Checking set-up.

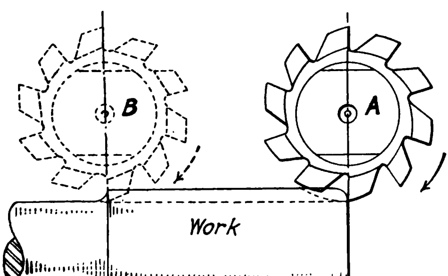


FIG. 223.—*A* cutting full depth of groove; *B*, end of cut, axis of cutter directly over shoulder.

206. Unequal Spacing or The Increment Cut.[1]—The general rules to be observed for cutting reamers with unequally spaced teeth are:

[1] For indexing movements for fluting reamers with unequal spacing see Table 9 page 408.

Number of flutes must be even.

Faces of teeth must be opposite.

If L is the largest space between two teeth and S the smallest, and the smallest space follows the largest; then the difference between L and S should not be over 6°.

The number of teeth on Brown & Sharpe solid hand reamers are as follows:

1/8 in. to 17/32 in.—(6); 9/16 in. to 13/32 in.—(8); 1 1/8 in. to 1 15/32 in.—(10); 1 1/2 in. to 2 1/16 in.—(12); 2 1/8 in. to 2 9/16 in.—(14); 2 5/8 in. to 3 in.—(16).

As an illustration of the operation let it be required to cut a 1 in. reamer with eight teeth (Fig. 224). Assume the cutter is set to give a radial tooth of approximately the proper depth or a little less and that a 39 index circle is being used.

It will be advisable to start each successive reamer from the original position of the index handle, for example, cut the first flute in each reamer when the index pin is in the numbered hole in the circle. (Note in Fig. 224 that "8th index" will bring work to original position.)

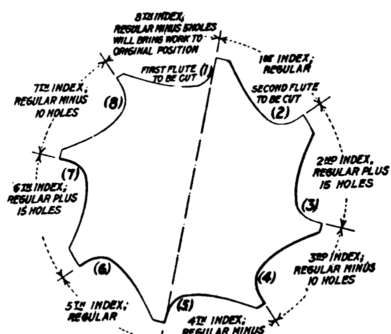


Fig. 224.—Shows moves for unequal spacing of reamer having eight teeth.

Proceed as follows:

1. Cut the first flute.
2. Index five turns (1st index regular) and cut second flute.
3. Index five turns plus fifteen holes (2nd index) and cut (3).
4. Index (from the hole the pin is now in) five turns minus ten holes (3rd index) and cut (4).
5. Index (from the hole the pin is now in) five turns minus five holes (4th index) and cut (5).

The fifth flute is now cut and the cutting face of (5) is exactly opposite the face of tooth (1).

The indexings for the teeth (6) (7) and (8) are duplicates of the movements 2nd, 3rd and 4th respectively, and the 8th index which is a duplicate of the 5th will bring the index handle to the original position.

Since opposite teeth are exactly opposite, many machinists prefer to cut a given tooth and then its opposite. Thus in Fig. 224, cut 1, then index 20 turns and cut 5; index for (6), cut 6, and index 20 turns and cut 2; index for (3) and cut 3 then 20 turns and cut 7, etc.

If the wider lands are too wide, lower the work a trifle and rotate the work to trim off the tooth, next trim opposite tooth; then arrange to trim back of another tooth and its opposite, etc.

207. Fluting Taper Reamers.—It is obvious that to mill taper work, the center line of the work must be out of parallel with the cutting line. The best method of milling tapers is to arrange the index centers on the tilting table (Fig. 156), which is readily adjusted to bring the "cutting line" the necessary amount out of parallel with the center line of the work without disturbing the alignment of the index centers.

The tilting table is a very special fixture not often available and the usual method of milling tapers is either to elevate the tailstock center or lower the index head spindle a sufficient amount to bring the cutting line horizontal.

When setting up to flute a taper reamer the cut and try method is probably the quickest and best, provided care and judgment are exercised. The lands on a taper reamer are usually a trifle wider at the large end than at the small end, but even so the flute is wider and deeper at the large end. Consequently the top of the reamer when set up is not horizontal but is a trifle higher at the large end.

Assuming the work to be adjusted vertically and laterally to give a radial tooth on the small end (as explained in paragraph 205) the preliminary adjustment for inclination of work will appear as in Fig. 225, with the point *a* of the reamer a trifle higher than *b* to cut the tooth deeper toward the large end, how much deeper depending on the amount of taper, number of teeth, etc. It is a good plan for the beginner to proceed as

follows: After setting the reamer as nearly right as may be judged, cut a short distance in two adjacent teeth at the small end and get the land the desired width. Set the vertical graduation at zero. Lower the table and run the work under the cutter until it is in position at the end of the cut (exactly over the shoulder at the large end of reamer). Then by raising the table, take two adjacent cuts until the land between is of the right width for this end of the tooth. Note the graduation

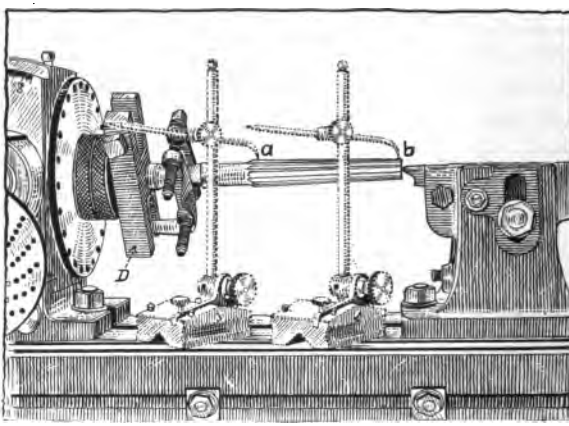


FIG. 225.—Set-up for milling flutes in taper reamer. A reamer already milled may be used to show that although the index head center is depressed to bring the bottom of the groove horizontal, that is, in the "line of cut," the cutting edge at *a* will still be higher than at *b*.

First adjust the head center until the bottom of the groove is horizontal as indicated by the surface gage, then adjust the scriber to touch the edge of the tooth at *a* and moving the surface gage to position *b* note the space at *b*.

Further, index for half the teeth and note that for each tooth the tail of the dog is in a slightly different position in the slot in the driver *D*. This shows that the work will be cramped unless the tail binding screw is loosened before each indexing.

on vertical adjustment; if the same as on small end the set-up is right. If incorrect, the readjustment of the center up or down may be made until the bottom of the groove at each end feels the same with the surface gage. If a sample reamer is at hand it may be profitable for the beginner to set up the sample and then substitute the reamer he is to cut.

If a regular bent tail dog or clamp dog is used, it will be necessary before each indexing to loosen the screw which clamps the tail of the dog in the driver; otherwise the work is likely to become cramped and possibly sprung.

The milling machine dog illustrated in Fig. 226 is very useful, especially in milling tapers. The construction eliminates the

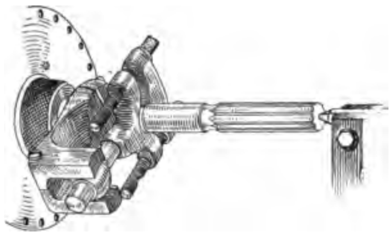


FIG. 226.—Milling machine dog. The feature of this dog is the ball and socket drive which prevents any tendency to cramp the work. (*Ready Tool Co.*)

necessity of adjusting any clamping screw since all likelihood of shake in the driver or cramping or springing the work is avoided.

208. Drilling and Boring in a Milling Machine.—Drilling and boring may often be efficiently accomplished in a milling

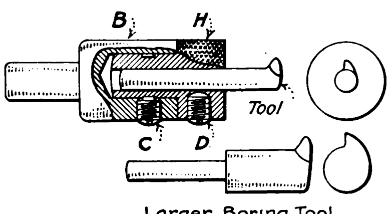


FIG. 227.—Eccentric boring tool holder and tools.

machine especially in jig work, or work of like nature (Fig. 155). The spacing between the holes may be obtained by means of the graduations on the feed screws or the holes in the smaller circular jigs may be spaced by indexing.

Various adjustable boring tool holders are manufactured. Figure 227 shows one type that may be easily and quickly

made. It may be provided with a taper shank to fit a collet or with a straight shank and held in a chuck.

The holder *H* is provided with a stem which is turned eccentric 1/16 in. off center to fit the hole bored 1/16 in. off center in the body *B*. A hole of perhaps 1/4 in. or 5/16 in. diameter is provided through the center of the holder and on through the stem to receive the shank of the boring tool which may be of any required length or size.

208A. Feeding with the Index Handle.—The index head worm and wormwheel movement is frequently used for *feeding* the work against the revolving cutter. Figure 228 shows three

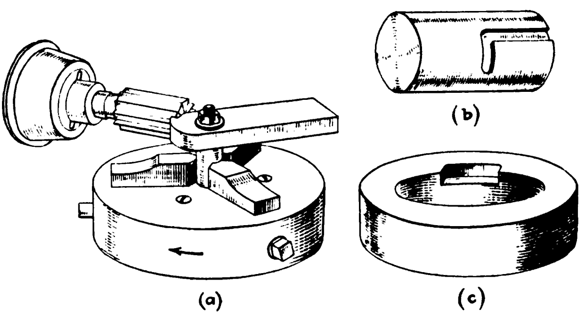


FIG. 228.—Shows work *fed* with index handle.

types of jobs that are easily accomplished in this way; (*a*) illustrates how the end of the work may be milled to a given radius; (*b*) shows a cylinder in which a groove has been milled lengthwise by the regular feed and then a continuation of the groove at right angles milled by feeding with the index handle; (*c*) shows a piece having a recess cut to a given depth part way around the hole.

Questions on Cutting a Spur Gear

1. If the gear blank is to be mounted on a mandrel for milling the teeth, why do you put oil on the mandrel before forcing it in the hole?

2. Why must the index centers be in line?

3. How will you arrange the sector? Why?

4. In which direction do you turn the index handle? Why?

5. How do you select the proper cutter? What do the letters and figures stamped in the cutter indicate? (See p. 369 and 374.)

6. How is the cutter set approximately central by means of the dead center? By means of a square against the dead center?

7. How is the cutter set approximately central by cutting a very small spot on top of the blank and locating the cutter to line with the spot?

8. How do you determine whether the cutter is central by cutting a groove, say two-thirds of the depth of the tooth, than reversing the work end for end, painting the groove with blue vitriol and noting where the cutter touches the sides of the groove when re-cut with the same setting?

9. Why do you leave the dog off when re-cutting the groove as in Question 8?

10. Why are screws provided to clamp the tail of the dog? How tight should the tail be clamped? Give reason.

11. How do you calculate the number of revolutions of the spindle to give the proper cutting speed for this job?

12. How do you determine the proper roughing feed? Finishing feed?

13. How much stock do you leave for a finishing chip?

14. How do you determine the depth of the cut to be made to give the correct gear tooth?

15. Is it good practice for the beginner to nick the teeth all around before cutting the gear? Give reason.

16. What is meant by a formed cutter? Is this gear cutter a formed cutter?

17. How should the formed cutter be ground to preserve the original shape of the cutting edge? Why?

18. What is a fly cutter? When is it advantageous to make and use a fly cutter? How is a fly cutter held?

19. If, for example, a new gear was needed on a repair job and no cutter of the proper pitch was immediately available could a fly cutter be made quickly that would answer to cut the gear?

Questions on Fluting Taps and Reamers, Boring, Etc.

1. When may it be economical to make taps and reamers instead of buying them?

2. Why is an angular cutter inferior to a special double angle cutter for fluting reamers?

3. Why is it necessary to off-set the work from under the center of the cutter?

4. Why, do you suppose, is the "cut and try" method of "setting the cutter" advocated by machinists?

5. When setting up, if the radial line of the layout is split, but the land is too wide, what correction is made?

6. What is the advantage of an increment cut reamer? Why are the opposite teeth milled exactly opposite? Is this necessary in a taper reamer?

7. How may the index centers be adjusted to mill the flutes in a taper reamer?

8. Explain the disadvantage of using a bent tail dog or a clamp dog when milling tapered work.

9. If you had a sample taper reamer to duplicate, how would you use a surface gage when adjusting the heights of the index centers? Would you set the surface gage pointer to the bottom of the groove or on the land of the tooth? Why?

10. If you had no sample, how would you use the surface gage?

11. Explain how one may do drilling, boring and reaming in a milling machine.

12. What is the advantage of an adjustable boring tool holder?

13. How may the indexing device be used for feeding the work?

14. Does the chuck screw on the spindle R. H. or L. H.?

15. What precautions would you suggest to avoid the tendency of the chuck to loosen under the pressure of the cut?

CHAPTER XIII

SPIRAL MILLING

209. Introduction.—There are certain operations in machine shop work which seem to appeal to the student or apprentice as being particularly interesting and worth while. One of them is cutting a thread in a lathe and another is milling a spiral in the milling machine. Both *are* interesting and both *are* well worth while because each of them involves straight thinking and sound reasoning and perhaps the intelligent accomplishment of either serves to develop the knowledge and skill of the student to a greater degree than any other single operation in either machine.

Spiral work includes the milling of spiral milling cutters, counterbores, twist drills, spiral gears, cams with spiral grooves, etc. In the manufacture of these articles special machines are used but any of them of a special nature or that are required quickly in small lots may be profitably made in the universal milling machine.

There are points of similarity in cutting a thread and milling a spiral. In cutting a thread the tool moves a certain distance while the work revolves once and this distance is the *lead* of the thread and is governed by the "change gears" used. The same is true of milling a spiral, only it may be more proper to say that while the work is feeding against the cutter, it is caused to revolve, and the distance it would have to feed in order to revolve once is the "lead" of the spiral. While the lead of a thread is usually short in proportion to the diameter and length of the thread, the lead of a spiral is usually long in proportion to the diameter and length. For example, the lead of a $\frac{7}{8}$ in. diameter standard thread is $\frac{1}{9}$ in. (having 9 threads per inch) and the lead of a standard $\frac{7}{8}$ in.

counterbore (cutter head about 1 in. long) cut with a spiral flute is 10 inches.

Setting up the machine for milling a spiral involves a knowledge of several mechanical principles. In the following pages the principles underlying the operation of spiral milling are first set forth as brief descriptions of the essential features. These features are then discussed in detail. To obtain a general survey of the subject read through carefully, and then, if possible while setting up and performing the operation, study each paragraph until the principle is thoroughly understood.

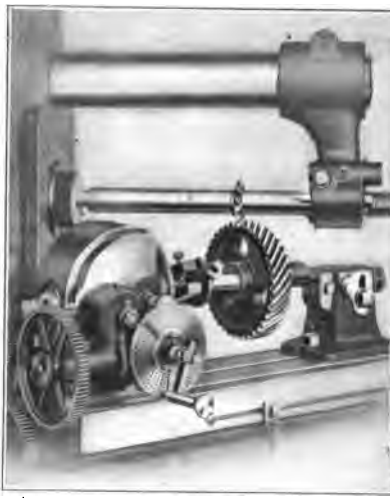


Fig. 229.—Milling a spiral gear.

210. The Spiral.—A spiral is a line generated by the progressive rotation of a point around an axis. When the path of rotation is in a plane it is called a plane spiral. A watch spring is an example of a plane spiral. If the convolutions of a spiral do not lie in a plane but form the shape of a cone it is known as a conical spiral. If this line is wound about a *cylinder* it is a *helix*, that is, what in machine shop work is called a spiral, is, correctly speaking, a helix, but in the following text, common usage will be followed.

211. The Lead of a Spiral.—The lead of a spiral is the distance it advances in one revolution measured parallel with its axis, for example, if gearing is so arranged as to cause the work to revolve once if it were fed 6 in., the lead of the spiral is 6 in. The length of the work or the length of the cut taken, makes no difference; that is, a lead of 6 in. to one turn may be cut on work 3 in. long, or a spiral with a lead of 6 in. may

be cut 12 in. long. In the first case, the groove will go one-half around the work, and in the second case, it will go twice around the work. The lead, however, is the same in both cases.

In most of the spirals cut in the milling machine the lead is more than 1 in., usually several inches, therefore spirals are designated in terms of "lead in inches to one turn" or merely "lead," as 1.5 in. lead, 24 in. lead, etc.

212. Five Features of Spiral Milling.

First, the Gearing.—Assume a cutter is set to mill a groove in a cylinder and that as the work is fed longitudinally under the cutter, it is at the same time given a uniform rotary movement. The groove will be a "spiral." In order to mill a spiral it is necessary to cause the work to *rotate* uniformly *on* its axis, while it is being *fed* in the direction *parallel* to its axis. The design of the universal milling machine permits of obtaining these two movements in practically any desired ratio to each other, by means of gearing from the table feed screw to the worm shaft of the index head, similarly as threads of different leads may be cut in a lathe by using different change gears. The selection and arrangement of the change gears as well as a description of the permanent gears in the index head will presently be explained.

Second Feature: Right-hand and Left-hand Spirals.—A spiral, like a thread, may be right-hand or left-hand and the same definition applies. A right-hand thread or spiral turns or "twists" to the right as it advances; the left hand turns in the opposite direction (Fig. 240). An easy way of telling whether a thread or a spiral is right- or left-hand is to hold it with the axis in a horizontal position and note the slant of the groove; if it slants *down* towards the right it is right-hand, if down towards the left it is left-hand. For example, observe that a twist drill has a right-hand spiral.

Third Feature: Setting the Table.—If it is required to mill a ½ in. semi-circular spiral groove in a cylinder, a ½ in. convex cutter may be used. If the cutter is set up with its axis at right angles to the axis of the work, as shown in *a*, (Fig. 230), and the work is fed on a spiral, the groove, instead of having a ¼″

radius will have a radius about equal to one-half the diameter of the cutter. This is shown in *b*, (Fig. 230). In order to mill this spiral groove the same contour as the cutting edge of the cutter it is necessary, (1) to swivel the table of the machine to a certain required angle, or, (2) to set the cutter to this angle, using the universal milling attachment. The relative positions of the cutter and the work in either case (1) or (2) is illustrated in *c*. The angle is known as the angle of the helix (or spiral) and depends on *two* things, the *lead of the spiral*

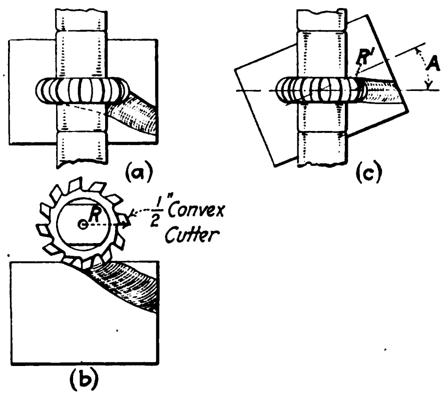


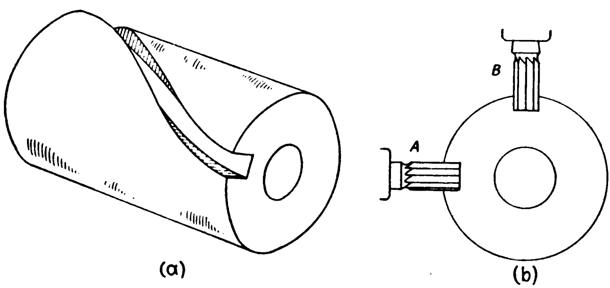
Fig. 230.—(*a*) Top view and (*b*) front view of spiral groove cut without swivelling the table. If the cutter is 2½ in. in diameter, the radius of the groove is about 1¼ in., approximately equal to *R*, the radius of the cutter. Note in (*c*), which represents the top view with the table swivelled to the angle of the helix *A*, that the radius of the groove is ¼ in. or equal to *R'*, the radius of the curve of the cutting edge.

and *the circumference of the work.* How this angle is calculated will presently be explained.

Fourth Feature: The Shape of the Cutter.—Figure 231*a* represents a spiral groove with parallel sides, milled in a cylinder to form a cylindrical cam. This groove may be cut with an end mill or a cotter mill as shown at *b*, but it will be impossible to produce such a groove of rectangular shape with a regular slotting cutter, because a cutter with parallel sides cannot fit in a curved slot. This is illustrated in *c*. The effect of attempting to use such a cutter for spiral milling is

shown in d; the sides of the slot will be ragged and the shape of the slot will not be rectangular. Further, an angle cutter with a straight side should not be used to cut spiral flutes for the reason that the teeth on the straight side will not produce a clean smooth cut but will have an effect similar to that shown in d (Fig. 231).

It is however, entirely feasible to use a cutter mounted on the arbor to mill a spiral groove provided the side cutting



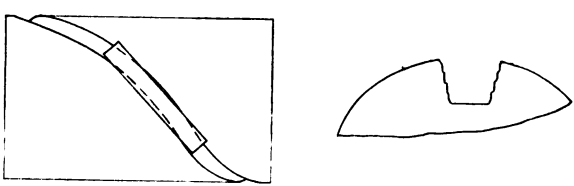


Fig. 231.—In a is shown a rectangular spiral groove and b illustrates how this cut may be made with an end mill held horizontally as at A or in a vertical spindle as at B. If it were attempted to mill such a groove with a narrow plain milling cutter or a slotting cutter as in C the groove when cut would not be rectangular but would appear about as shown somewhat enlarged at d.

edges incline more or less toward each other, for example, a double angle cutter, or a convex cutter, or a gear tooth cutter may be used to cut a spiral because no part of the cutting edge of any tooth of such a cutter touches the work except when it is taking a chip (Fig. 240, p. 289).

Fifth Feature: Circular Pitch and Normal Pitch.—The section (or shape) of a groove generated, or of the tooth formed by spiral milling is *normal* (that is, of true form), only when

viewed (measured) at right angles to the direction of the groove or tooth. The section of either as seen or measured on the end of the work is distorted; that is, the groove appears and is unlike the form of the cutter, and the tooth shape is correspondingly distorted when viewed at right angles to the axis of the work. This difference is shown graphically in Fig. 232, where *ABC* represents the circular pitch of a spiral gear, *AB* the tooth, and *BC* the tooth space. The dotted line *ab* shows the direction of the groove and the line *ADE* at right angles to the side of the tooth at *A* represents the normal pitch of the gear. It is obvious that the width of the groove as viewed on the end *BC* is greater than the width as viewed at *DE* and the depth being the same in both places the shapes are unlike. This feature is of extreme importance when milling spiral gears and must sometimes be considered when judging or gaging the shape of other spiral teeth or grooves.

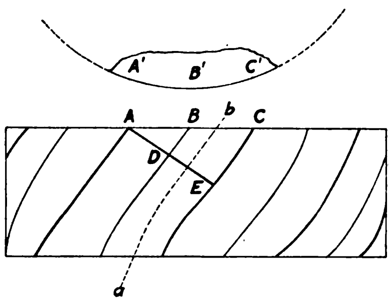


Fig. 232.

Questions on Spiral Milling 1

1. What do you understand by the term spiral? Is a thread a spiral?

2. What are the points of similarity of a thread and a spiral? What is the chief difference between the helical groove of a thread and the helical groove of a spiral milling cutter?

3. What is meant by the lead of a spiral? How is this distance usually expressed?

4. Why is it necessary, when milling a spiral, to cause the work to revolve slowly at the same time it is being fed?

5. How is the work caused to revolve while it is being fed?

6. Suppose the work would revolve once if it were fed 10 in., what would you change to give a lead of 20 in.?

7. The universal milling machine has a table with swivel construction? Why?

8. When is it necessary to set the table to an angle in spiral milling? When is it unnecessary?

9. State an easy way to tell a right-hand spiral from a left-hand spiral.

10. State why a regular slotting cutter cannot be used to cut a spiral groove of rectangular shape.

11. Is the angle of the flute or groove as measured on the end of a spiral milling cutter exactly the same as the angle of the cutter that produced it? Give reason.

213. The Gears Necessary for Spiral Milling.—Figures 233 and 234 show respectively a Brown & Sharpe index head and

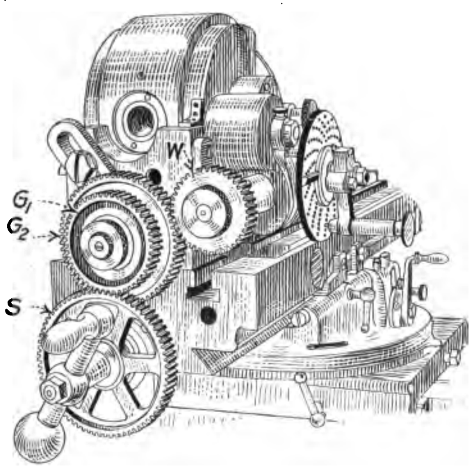


Fig. 233.—B. & S. spiral head arranged for spiral milling.

a Cincinnati index head arranged for spiral milling. It will be observed in either one, and as a matter of fact it is true in all standard universal milling machines, that motion from the table feed screw to the index head (gear *W*) is transmitted by spur gears. Certain of these gears are termed the "change gears" and are selected and arranged according to the spiral desired. For example, if the gear *W* revolves at the same speed as gear *S*, a spiral with a lead of 10 in. will be cut; if *W* goes twice as fast as *S* a lead of 5 in. will result; if half as fast a

lead of 20 in. will result. Before learning how to calculate the sizes of these gears for the various spirals it will perhaps be best to determine how a movement of the gear *W* causes the work to move. This motion is transmitted by gears which are a permanent part of a spiral head.[1] For this reason they may properly be referred to as the spiral head gearing.

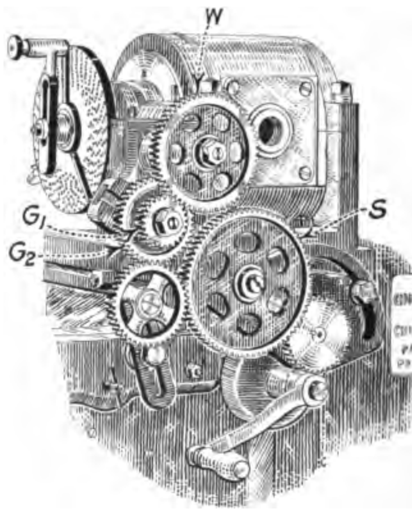


FIG. 234.—Cincinnati spiral head arranged for spiral milling.

214. Spiral Head Gearing.—The spiral head is a particularly ingenious and interesting mechanism. The underlying principle of the construction is the same for any standard make. The purpose is to cause the worm shaft (and consequently the work) to turn by power transmitted to the gear *W* (Figs. 233 and 234), without interfering in any way with the regular functions of the dividing head. To obtain this power movement, the index plate is (incidentally) caused to

[1] "Index head," "spiral head" and "dividing head" are used in different places to mean the same thing. A spiral head is an index head (or dividing head) which may be used for cutting spirals.

turn, consequently *it is necessary to disengage the index plate locking device when setting up for spiral milling.*

Because the shaft on which the gear W is mounted is at right angles to the wormshaft, the use of either bevel gears or spiral gears is necessary to transmit motion from the one to the other.

215. The Index Head with Bevel Gears.—The way in which *bevel* gears may be employed is illustrated in Fig. 235.

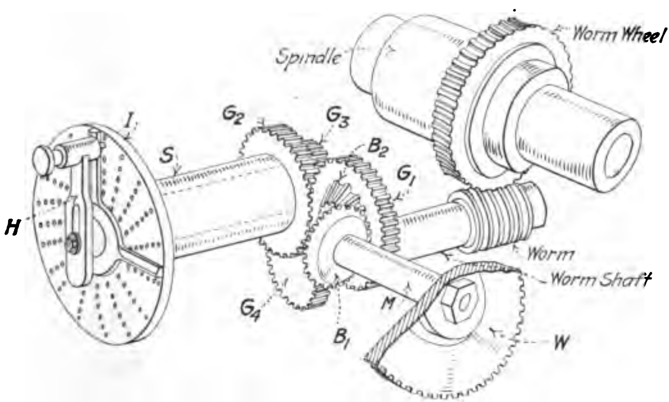


FIG. 235.—Spiral head gearing (Cincinnati). Motion transmitted from W through M to B_1 to B_2 to G_1 to G_2, through sleeve S to I to H, through shaft within S to G_3 to G_4, through worm shaft, worm and worm wheel to spindle and work.

Motion of the gear W causes motion of the miter gear B_1, both being keyed to the shaft M; B_1 engages B_2 which is fastened to G_1; the gear G_1 engages G_2 which is fastened to the sleeve S, to which is also fastened the index plate I, consequently when the gears are in motion the index plate revolves. The index crank H and the gear G_3 are fastened to the same shaft, therefore if the index pin is in a hole in the plate and moves with the plate the gear G_3 moves. The gear G_3 engages G_4 which is keyed to the wormshaft and thus transmits motion to the worm and wormwheel. It will be observed that the pairs of gears B_1 and B_2, G_1 and G_2 also

G_3 and G_4 are equal, therefore 40 turns of the auxiliary shaft M will cause one turn of the wormwheel.

Ordinarily, for indexing, only the gears G_3 and G_4 are used; the index plate is held in position by a stop and does not turn. When the index crank is turned its shaft turns freely through the sleeve S, moving the gears G_3 and G_4 and causing the worm and worm-wheel to move, thus indexing the work the required amount.

216. The Index Head with Spiral Gears.—In the cut (Fig. 236) is shown the arrangement of the gearing in an index head

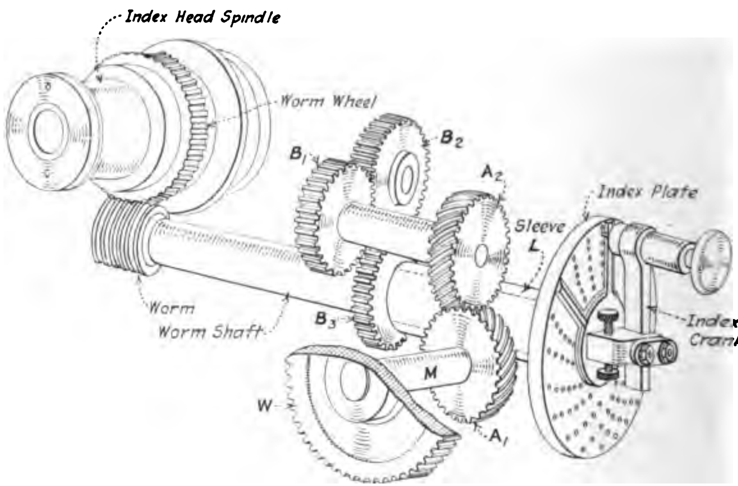


FIG. 236.—Spiral head gearing (B. & S.). Motion transmitted from W through M to A_1 to A_2 to B_1 and B_2 (idler) to B_3, through sleeve L to index plate to index crank to worm shaft, worm, worm wheel, spindle and work.

in which *spiral gears* are used to transmit the motion at right angles. The construction of the head is more compact than the cut indicates. This cut has been made with the idea of showing the arrangement more clearly.

Motion of the gear W on the shaft M is transmitted to the spiral gear A to the other spiral gear A_2 to spur gear B_1 to intermediate B_2 to B_3. The gear B_3 and the index plate are fastened to the sleeve L. Therefore, when B_3 revolves the

index plate revolves and when the index pin is in, the index crank is carried around with the plate and since the index crank is fastened to the wormshaft, this operates the worm and wormwheel. Remember when setting up that the *stop pin* must be withdrawn.

In the above arrangement, it will be noted that simple indexing of the piece being milled on a spiral is accomplished in the usual way. (Pull out the index pin, turn the index handle and the wormshaft turns in the sleeve L and causes the work to turn the required part of a revolution entirely independent of the gearing for the spiral). The idler gear B_2 is in the swivel center of the head and tilting the head in no way effects the engagement of the gears. The gears all have the same number of teeth so that 40 turns of W will cause one turn of the wormwheel.

In connection with a study of the gearing which may be regarded as a permanent part of the index head mechanism, there are three out-standing features.

First, the operation of indexing is entirely independent of the spiral mechanism, for example, after one groove of a spiral mill is cut the table is run back and the work indexed in the usual way for the next groove.

Second, the arrangement of the gears in the head is such that when not in use they in no way interfere with tilting the head, or with either simple or direct indexing.

Third, one turn of the auxiliary shaft on which the gear W is mounted causes one turn of the wormshaft and $\frac{1}{40}$ of a turn of the work, in other words the operation is exactly the same as if the gear W were mounted direct on the wormshaft, and in any discussion of the mechanism and in the calculations for the change gears for cutting any spiral, the gear W is spoken of as the "gear on worm."

217. Change Gears for Spiral Milling.—In Figs. 233 and 234 the gear S known as the *gear on screw* is keyed to the feed screw. G_1 and G_2 are respectively *first gear on stud* and *second gear on stud* (or first intermediate and second intermediate). They are both keyed to a sleeve which rotates freely on a stud

which is fastened in an adjustable bracket, and form the compound between S, the gear on screw, and W which in spiral milling is known as the *gear on worm.*

Thus a movement of the feed screw, besides causing the table to feed, may cause the work to revolve if gears are arranged to transmit motion from the feed screw to the worm shaft. The gears S, G_1, G_2 and W are the change gears. Twelve change gears are regularly furnished, and by using different combinations of gears, the ratio of the rotary movement of the work to the longitudinal movement of the table can be varied,

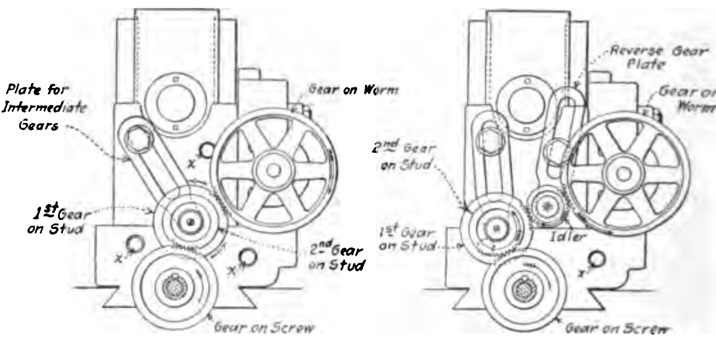


FIG. 237.—Brown & Sharpe change gears arranged *a* for right hand spiral, and *b* with idler introduced for cutting left hand spiral.

and spirals of various leads may be cut. Introducing an idler serves to change the direction of the driven gear consequently spirals may be either right-hand or left-hand.

The manner of arranging the change gears for spiral milling on the Brown & Sharpe milling machine is indicated in Fig. 237, *a* shows the arrangement when no idler is used and *b*, when an idler is used.

It will be noted that the gears on the stud and also the idler gear are mounted on adjustable brackets. Tapped holes are provided in the back of the index head and also in the end of the table for the cap screws used for holding these brackets.

The Cincinnati dividing head arranged for milling a spiral is illustrated in Fig. 234. The driving mechanism con-

sists of 12 change gears and an adjustable bracket or segment on which the necessary gears to transmit motion between the feed screw and the auxillary wormshaft may be arranged.

It will perhaps be well to call special attention here to the following: In the Cincinnati milling machine as in the Brown & Sharpe, the first intermediate drives the gear on worm, but its position on the stud is reversed, it is the *second* one put on. This may be true also of certain other machines. However if the machinist who is setting up the machine understands which gears are *driving* gears and which are *driven* he will have no trouble in setting any milling machine for the given spiral. The gear on the screw S is the initial *driving* gear and the "gear on worm" W is the final *driven* gear of the change gear train.

It will be observed that the four change gears make up a compound gear train; that is, two are driving gears and two are driven gears. Compound gearing is usually employed because with a given number of change gears a much larger range of combinations is possible than can be obtained with a simple gear train, and also, the very short center distance between the gear on screw and the gear on worm, makes compounding practicable for most of the leads to be cut.

The idler is neither a driving gear nor a driven gear. It is an *idler* gear and serves to change the direction of the gears which follow it in the train. The use of the idler varies with different machines; in some it is used when cutting right-hand and in others when cutting left-hand spirals.

218. Calculating the Gears for Spiral Milling.—In spiral milling if equal gears are used on the feed screw and worm, and these gears connected by an intermediate (two equal gears may be used on the stud to act as a single intermediate), the shaft M, (Figs. 235 and 236), will revolve at the same speed as the feed screw. Therefore, when the feed screw revolves 40 times the wormshaft revolves 40 times and *the work revolves once.* At the same time, since the screw revolves 40 times, the table moves a certain distance, usually 10 in. In spiral milling this distance is known as the "*lead of the machine.*"

(Most milling machines have a $\frac{1}{4}$ in. pitch feed screw and 40 revolutions of the feed screw will feed the table $40 \times \frac{1}{4}$ in. or 10 in.)

In spiral milling, the formula for calculating the gears to cut any spiral is similar to the formula for calculating the gears for thread cutting in a lathe, the constant in spirals being the "lead of the machine." The formula may be expressed as a proportion, thus the lead of the machine is to the lead of the spiral required as the product of the driving gears is to the product of the driven gears. Expressing the ratios as fractions:

$$\frac{\text{lead of machine}}{\text{lead of spiral desired}} = \frac{\text{driving gears}}{\text{driven gears}}$$

To illustrate the calculations two examples are given:

Example 1.—Spiral with a lead of 12 in. required.

Using the formula and substituting values

$$\frac{\text{lead of machine (10)}}{\text{lead of spiral required (12)}} = \frac{\text{driving gears}}{\text{driven gears}}$$

That is,

$$\text{The fraction } \tfrac{10}{12} = \text{ratio } \frac{\text{driving gears}}{\text{driven gears}}$$

Now if a simple gear train (one driving and one driven gear) were to be used and a 10-tooth gear for the screw and a 12-tooth gear for the worm were available such an arrangement could be used. However, no such gears are at hand and further it is desired in this example to use four gears as a compound gear train because in most cases, if not in this, a compound gear train is advisable.

In order to select these gears the fraction $\frac{10}{12}$ is split into two fractions whose product equals $\frac{10}{12}$, for example $\frac{5}{4} \times \frac{2}{3}$, the terms of which will represent the two pairs of change gears.

If it were possible to obtain and use gears with 5 teeth and 2 teeth, they would be the driving gears and the 4-tooth and 3-tooth gears would be the driven gears. Of course this is impossible, therefore, both the numerator and denominator

of either fraction ($\frac{5}{4}$ and $\frac{2}{3}$) are multiplied by any number whole or mixed,[1] that will give a numerator and denominator that corresponds to the numbers of the teeth on two of the available change gears.

Thus, multiplying both the numerator and denominator of the first fraction $\frac{5}{4}$ by 8 for trial, and of the second fraction $\frac{2}{3}$ by 24 for trial gives

$$\frac{5 \times 8}{4 \times 8} = \frac{40}{32} \text{ and } \frac{2 \times 24}{3 \times 24} = \frac{48}{72}$$

or

$$\frac{5 \times 2}{4 \times 3} = \frac{40 \times 48}{32 \times 72} = \frac{\text{driving gears}}{\text{driven gears}}$$

That is, gears 40 and 48 may be used for the driving gears and 32 and 72 for the driven gears.

These gears may be arranged in the B. & S. machine for example as:

72 gear on worm (driven gear)
40 first gear on stud (driving gear)
32 second gear on stud (driven gear)
48 gear on screw (driving gear)

Or they may be arranged otherwise *if* the driving gears are arranged to drive and the driven gears are arranged to follow.

Example 2.—Spiral of 27 in. lead required.

$$\frac{\text{lead of machine (10)}}{\text{lead of spiral required (27)}} = \frac{\text{driving gears}}{\text{driven gears}}$$

$$\frac{10}{27} = \frac{2 \times 5}{3 \times 9} = \frac{32 \times 40}{48 \times 72}$$

72 gear on worm (driven gear)
32 first gear on stud (driving gear)
48 second gear on stud (driven gear)
40 gear on screw (driving gear)

NOTE.—Remember when using the above formula that the gear on the screw is the initial *driving* gear.

[1] Multiplying both the numerator and denominator of a fraction by the same number does not change the value of the fraction.

As a matter of fact from a practical standpoint, the cards furnished with the machine will show the gears to use and the angles to set the table for a great variety of spirals. Further, all leads possible with the combinations of gears that may be used have been calculated and published by Brown & Sharpe Manufacturing Co. and also by the Cincinnati Milling Machine Co. However, the man who is always satisfied to let someone else do his thinking for him is always cheap help. What would he do if one of the gears were lost or broken?

219. The Angle of the Helix or Spiral.—As previously stated (paragraph 212) in order to cut a spiral otherwise than with an end mill, it is necessary to set the table or the cutter to a certain angle, that is, to the angle of the helix (or spiral) being cut.

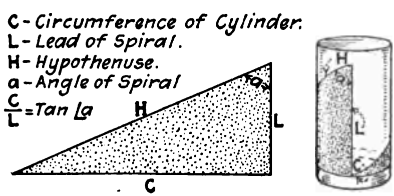


FIG. 238.

The development of a spiral, in other words the path of the spiral, may be represented by the path of the hypothenuse of a paper right angle triangle (Fig. 238), when wound about a cylinder as shown. The adjacent sides *L* and *C* must equal respectively the *lead* of the spiral and the *circumference* of the cylinder, and the side *L* is parallel to the axis of the cylinder. The angle included between the sides *H* and *L* is the angle of the spiral and this is the angle to which the table must be set, or if using the universal milling attachment the angle to which the cutter must be set.

The angle of the spiral may be ascertained in two ways; graphically that is, by making a drawing of a right triangle similar to that shown in Fig. 238, *L* being equal to the lead, and *C* equal to the circumference of the work. The angle *a* may be measured with a protractor.

The second method, which is more accurate and often more convenient, involves mathematical calculations and the use of a table of tangents.

The calculations for the parts of a helix (or "spiral")

are made with the use of trigonometric tables.[1] In the right triangle Fig. 238 the circumference of the cylinder corresponds to the *side opposite* the angle, and the lead corresponds to the *side adjacent* the angle. Hence the following rules:

RULE I.—To find the angle of the spiral having given the circumference of work (pitch circumference in spiral gears) and the lead; circumference divided by lead equals the tangent of the spiral angle or $\left(\frac{C}{L} = \tan \text{ angle } a\right)$.

Example.—Diameter of blank = 3 in. (*circumference* equals 9.42); lead = 24 in. What is the angle of the spiral?

Solution.—$\frac{9.42}{24} = .392 = \tan 21° 25'$ or $21\frac{1}{2}°$ near enough.

RULE II.—To find the lead having given the circumference of blank and the spiral angle: Divide the circumference by the tangent of the angle, or $\left(L = \frac{C}{\tan \text{ angle } a}\right)$.

Example.—Diameter equals $3\frac{1}{2}$ (circumference equals 10.09); angle of spiral equals 26°. What is the lead?

Solution.—Tangent of angle of 26° equals .488. Dividing circumference 10.90 by .488 equals 22.5 or lead equals $22\frac{1}{2}''$.

Setting the Table for R. H. Spiral and L. H. Spiral.—For a *right-hand spiral* move the zero line on the swivel plate to the right of the zero line on the saddle; in the opposite direction for a *left-hand spiral.*

220. Milling Steep Spirals.—It is often advantageous to use the universal milling attachment, especially when milling steep (short lead) spirals (Fig. 239). When this attachment is used for spiral milling, the table is not swivelled, but it will be necessary to set the cutter to the angle of the spiral by swivelling the attachment. The work is brought into its proper position with reference to the cutter, *after the cutter is swivelled.*

The rack milling attachment or the vertical milling attach-

[1] For formulas and tables see pages 418 to 423. For simple explanation of Shop Trig see "American Machinist's Hand Book" (McGraw-Hill), BURNHAM'S "Mathematics for Machinists" (Wiley & Son).

ment may be used for milling short lead spirals. Wh using either of these attachments the work table is swivel to an angle equal to the *compliment* of the angle of spiral.

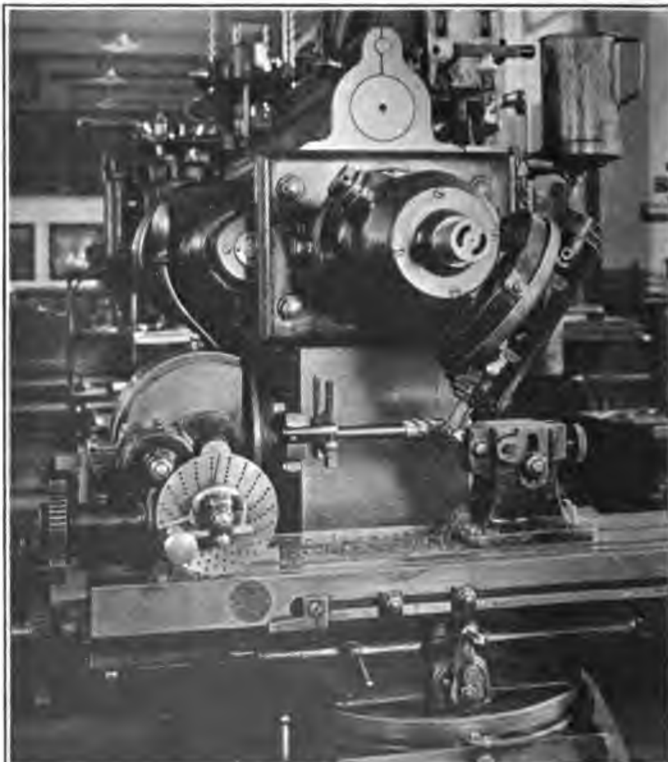


FIG. 239.—Milling a steep spiral. (*Dickinson High School.*)

221. To Use the Card Furnished with the Machine.—(Car marked, "Table of Approximate Angle for Cutting Spirals' or "Table of Change Gears, Angles and Leads for Cuttin Spirals.")

1. To find the gears to use:

In column marked "lead in inches" find the required lead

and in line with the lead, the four gears that will give this lead are shown. The position of each gear is shown at the top of its column—as "gear on worm," "first gear on stud," "second gear on stud" and "gear on screw."

2. To find the angle at which to set the table:

Near the top of the card under the heading "Diameter of Work" or "Diameter of Cutter, Drill, or Mill" are several columns captioned by figures representing various diameters from 1/8 to 6 in. In these vertical columns are figures representing the various angles to which the table must be swiveled to give the proper setting of a particular diameter of work for any spiral. The number of degrees the table must be swiveled is found where the horizontal column to the right of the "lead" meets the vertical column under the "diameter."

Example.—Work 2½ in. diameter, lead 22.50.

1. Find under "lead in inches to one turn" 22.50. In the same line are four gears; 72, gear on worm; 28, first gear on stud; 56, second gear on stud; 64, gear on screw.

2. Lay a card or a rule just under the horizontal column of figures to the right of the lead 22.50, then follow down column under 2½ diameter until the figure opposite 22.50 is reached and find that the table should be set around 19¼°.

Questions on Spiral Milling II

1. What is the purpose of the "change gears" in spiral milling? How many are there?

2. What do you understand by "the spiral head gearing?"

3. Why are either bevel gears or spiral gears used in the spiral head gearing?

4. Why is it necessary to withdraw the stop pin or disengage the index plate locking devise whatever it may be when cutting a spiral?

5. Make a sketch which will show the way in which motion is transmitted from the table feed screw to the spiral head spindle.

6. Set up the machine for any convenient lead of spiral. In the change gear train which is the initial driving gear? Is there a compound of two gears used? Is an idler used? Which is the final driven gear?

7. As for the set up in the preceding question. Divide 10 times the product of the driven gears by the product of the driving gears. What is the answer equal to?

8. If it were possible to transpose the driving gears and still get the proper engagement of gears in the train, would this change the spiral? Explain.

9. Suppose the card furnished with the machine calls for certain gears to cut a given lead and one of the gears is lost, what could you do?

10. The card furnished with Brown & Sharpe milling machine calls for the gears 56, 32, 40 and 100 to cut a lead of 7 in. The gears 56, 40, 32 and 64 if properly arranged may be used? How should they be arranged?

11. In the first case (question 10) 32 is a driving gear and 40 is a driven gear. Is this true in the second case? Explain.

12. On the card furnished with Brown & Sharpe milling machine, the angle of the spiral for a lead of 7 in. on work 1 in. in diameter is given as 24½° and for work 2 in. in diameter the angle is 42°. Cut out triangles as explained in paragraph 219 and check results.

13. Cut out a triangle to show the angle of the spiral for a lead of 14 in. on work 2 in. in diameter. How does this angle compare with the angle for work of the same diameter but half the lead (question 12)?

14. State the *two* things that determine of the angle of the spiral.

15. Which direction do you swivel the table for a right-hand spiral. Why?

16. Frequently a certain angle of spiral is required on a given diameter. How would you find the lead? How would you calculate the gears to use?

222. Example Selected: Spiral Milling Cutter.—Operations in spiral milling which are not uncommon in most machine shops and which offer excellent practice, are cutting the flutes in spiral milling cutters, spiral end mills and counterbores. These operations involve less mathematics than cutting either cams or spiral gears,[1] but they do require the same knowledge of spiral milling and as much if not more skill in the set up.

The reason that the set-up for cutting a spiral mill is more difficult is because the flute is not symmetrical, as is the cam groove or the gear tooth space. To set the cutter for a spiral

[1] For extended descriptions of the milling of spiral gears and cams, see the following: "A Treatise on Milling and Milling Machines," published by Cincinnati Milling Machine Co., "Treatise on Gearing," and "Treatise on Milling" published by Brown & Sharpe Manufacturing Co.

gear, for example, it is only necessary to set the cutter central with the blank before swivelling the table to the required angle, while to set a double angle cutter to produce either a radial tooth, as is usually required on finishing cutters, or a tooth with 10° or 15° rake for roughing cutters, it is necessary to off-set the work under the cutter a certain distance. Since the distance the work is off-set depends (1) on the angle of the cutter, (2) the diameter of the blank, (3) the number of teeth and (4) whether a radial tooth face or an undercut tooth face is required, no set rule for the offset can be given. It is best to lay out lines indicating the faces of two adjacent teeth and proceed carefully to cut to the layout. (Explained p. 292.)

223. Reason for Double Angle Cutters.—When an angular shaped groove is desired, as in a spiral milling cutter, it is impossible to produce a radial tooth or a smooth surface with an "angular" cutter because such a cutter has one straight side and will act similarly to the cutter *c* in Fig. 231. A "double angle" cutter should be used. The groove clearance of a double angle cutter is illustrated in Fig. 240. It will be noted that after the slot is cut to depth as at *a* that the teeth back of *a* do not touch the sides of the groove at all. The fact that the angular teeth in this way clear the groove already cut makes it possible to use this kind of cutter for spiral milling. For fluting spiral milling cutters 2½ in. diameter or more and up to a 25° spiral angle a double angle cutter with a 12° angle on one side and either 40°, 48°, or 53° angle on the other side may be used. To cut a short lead spiral on a small diameter for example a 4.26 lead on a 1 in. end mill (Fig. 239) will require a greater angle than 12° on the cutter. It will depend of course on the shape of the tooth

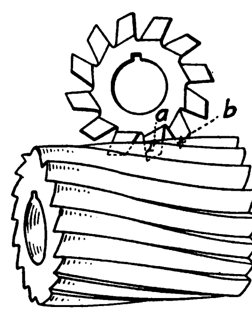


FIG. 240.—Hold a double angle cutter in the groove of a spiral milling cutter with the cutting edges *a* vertical and touching the sides of the groove, then observe the amount of clearance (space) between the cutting edges *b* and the groove.

desired whether a cutter with included angle of 52°, 60°, or 65° is used. In any case the steep side should form the face of the tooth.

224. Use of R. H. and L. H. Double Angle Cutters.—A cutter should be selected, right-hand or left-hand as the case may be, which in operation will free the steep side of the groove, that is, the blank being milled should turn in a direction away from the 12° side of the cutter. This will give a cleaner, smoother surface to the front (or face) of the tooth being milled. The correct set-up for milling right-hand and left-hand spiral cutters is shown in Fig. 241.

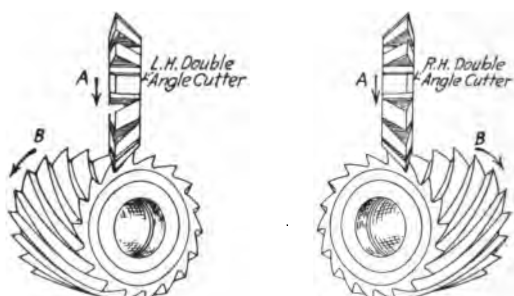


FIG. 241.— Illustrates the difference in the setting of the table and also in the cutter used when milling right hand and left hand spirals. Both views are shown as from the foot-stock end of the table. Arrow *A* denotes the direction of the cutter, and arrow *B* the direction of the rotation of the blank as the spiral groove is being milled.

225. Setting the Cutter for Spiral Milling.—In the universal milling machine, the axis of the cutter and the pivot center of the table are in the same vertical plane. It is only in this plane that the cutter cuts its full depth (or its shape) in the work.

This is one of the most important points to remember in setting up for spiral milling. Suppose the machinist sets up to split a line when the edge of the blank is, say, a quarter of an inch in front of the axis of cutter. Not only is the cut made deeper when the work is fed the quarter of an inch, but the

work *rotates* at the same time it is *fed* and of course the line rotates with the work and its relation to the cutter is changed.

When milling spiral flutes that are symmetrical, that is, alike on both sides, (for example the teeth on a spiral gear), *care must be taken to set the work centrally under the cutter before the table is swivelled.*

In setting up for spiral milling when the groove is not symmetrical, for instance the flute in a milling cutter, it is customary to draw lines on the end of the first blank to be milled which will indicate the relative positions of the faces of two adjacent teeth. These lines are scribed after the blank is in position between centers as will be explained later. The end of the blank is then arranged directly over the pivot center of the table, that is, directly under the axis of the cutter; next the table is swivelled and then the work may be adjusted on its axis or crosswise or vertically (but *not* longitudinally) under the revolving cutter until the cut made is according to the lay out.

NOTE.—The greater the angle of the spiral the further the work table must be moved away from the column in order to allow the table to be swivelled the required amount. Also the cutter must be arranged on the arbor practically over the pivot center of the table. Since guessing at the position of the cutter on the arbor is likely to cause delay, the following procedure is advisable:

1. Place the work between centers.
2. Swivel the table to the angle of the spiral.
3. Move the table laterally ("cross feed") until there is ½ in. or so clearance between the table and the column.
4. Tighten the cutter on the arbor in substantially its proper position over the work. Now it is assured that the cutter is in the right place on the arbor.
5. Bring the table back to straight (zero) and set the end of the work under the axis of the cutter. This is in order to have the cutter in such a position, when the work is being adjusted, that the full depth and exact shape of the groove that

will be cut may be noted. It is easier to judge the proper setting when the table is straight.

6. Swivel the table to the angle of the spiral, and tighten the clamping screws.

7. Proceed to make the necessary layout and adjustments as explained in the following paragraphs.

226. The Operation of Setting a Double Angle Cutter.—Many spiral milling cutters are milled with a 48°–12° angle cutter. Assuming such a cutter is used, the method of procedure for lay out etc. would be as follows: Apply blue vitriol on the end of the blank and with a surface gage, set to height of index centers, scribe a line (1) as shown in *a* (Fig.

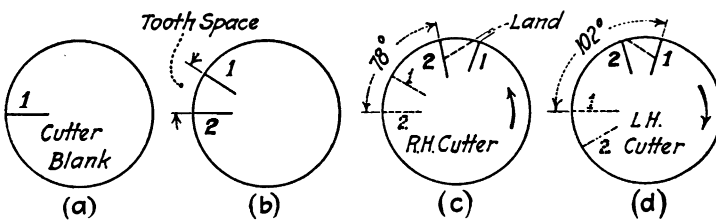


Fig. 242.—Illustrates method of laying out two adjacent tooth face lines and indexing these lines to their proper position. (These views are from foot-stock end with index head on left end of table, as in B. & S. machine). Remember when indexing for a certain number of degrees that one turn of the index handle moves the work nine degrees.

242). Index for one tooth space and scribe another line (2) as shown in *b*, these two lines represent the faces of two adjacent teeth. When cutting the groove between these two teeth, the cutter and the work must be arranged in such a way that one side of the cutter (the 12° side) will split one radial line and the other side of the cutter will leave an uncut space, equal to the land required, between the groove and the line representing the face of the next tooth. This is shown in *c* where the lines (1) and (2) have been rotated to position under the cutter. When rotating the blank to bring the lines (1) and (2) in position it makes a great difference whether a right-hand or a left-hand cutter is being milled. This is illustrated in *c* and *d* (Fig. 242). If a right-hand spiral is to be cut the

work will have to be revolved as illustrated in *c*. If the line (2) is moved (indexed) 78° (90° minus 12°) it will bring this line in position for the radial face of the tooth. If the work is moved transversely and vertically until the cut made splits line (2) and approaches close enough to line (1) to leave the amount of land desired on the tooth, then the setting is correct.

If a left-hand spiral is to be cut the method of procedure after drawing the two lines as illustrated in *d* is as follows:

Rotate the work *back* one tooth space to bring the line (1) on center (as it was originally, see *a*), then rotate it forward again 102° (90° plus 12°) (see *d*, Fig. 242). This will bring the line (1) in position for the radial face of the first tooth and line (2) one tooth space distant so that the amount of the land may be easily judged.

NOTE.—Above are directions which apply to Brown & Sharpe milling machine and all machines where the index head is on the left end of the work table. When head is on the right end of the work table as in the Cincinnati milling machine, the directions for layout for right-hand and left-hand spiral milling cutters are reversed.

227. A Typical Spiral Milling Job, Step by Step.—Required to cut a right-hand spiral milling cutter 2½ in. diameter, 18 teeth, radial face, 1/32 in. land, 12° angle of spiral with 60° (48°–12°) double angle cutter.

1. Obtain mandrel, dog, arbor, cutter (48°–12°), surface gage, blue vitriol, etc.

2. Oil the mandrel and press it firmly in cutter blank.

3. Thoroughly clean and dry the hole in the spindle and the shank of the arbor and drive (or draw) home *tight*.

4. Arrange sector with correct number of spaces between the arms, and *withdraw stop-pin*.

5. Arrange proper change gears and try hand feed *to be sure spiral mechanism operates freely*.

$$\text{Lead} = \frac{\text{circumference}}{\text{tan of spiral angle}} = \text{in this case } \frac{2.5 \times 3.14}{\text{tan of angle of } 12^\circ}$$

$= \dfrac{7.85}{.213} = 36.8$ in. The nearest lead with available gears on

Brown & Sharpe milling machine is 37.04; on Cincinnati milling machine nearest lead is 36. Either is near enough.

6. Loosen swivel clamping bolts, temporarily set table to angle of spiral and feed crosswise until table clears face of column by about half an inch.

7. Arrange cutter blank between centers, and feed table until end of blank is approximately under axis of cutter arbor.

8. Arrange cutter approximately central (crosswise) over end of blank and tighten cutter on arbor securely.

9. Swivel the table back to straight (zero) and feed longitudinally until end of blank is exactly under axis of cutter.

10. Put blue vitriol solution on end of blank where lines are to be scribed.

11. With point of scriber on center draw radial line (1) (Fig. 242). Index one tooth space and draw line (2) then index as per directions given in paragraph 226 according to the arrangement of the head, left or right end of table.

12. Swivel table to correct angle.

13. Cut tooth space to depth, splitting tooth-face line and leaving $\frac{1}{32}$ in. land. To do this it should only be necessary to adjust the work vertically and crosswise. The index handle and the longitudinal table feed should not be touched.

14. Either two cuts (roughing and finishing) or one may be taken as seems advisable. When table is adjusted for the finishing cut set the graduated collars on the cross feed and vertical feed at zero.

NOTE.—The difference between the normal pitch and circular pitch (paragraph 212) as regards the line (1) in this case is practically negligible.

Cautions.—Be especially careful when milling spirals to have the work tight on the mandrel, the cutter arbor tight in the spindle, and the dog securely fastened.

Be sure the dog has plenty of room to turn and will not bring up against the arbor at the end of any cut.

Remember to lower the table before running back and to raise it again before starting the next cut.

Questions on Spiral Milling III

1. Do you know how to read the card furnished with the machine? Are you satisfied merely to know how to read it?

2. What is a double angle cutter? Why is a "double angle" cutter better for milling spirals than a cutter with one angle?

3. Make a sketch that will show why a double angle cutter must be "off-set" from center in order to cut a radial tooth.

4. State why it is impossible to give a rule for the amount of off-set?

5. Why are double angle cutters made in both R. H. and L. H. forms? How do you tell one from the other?

6. What do you understand by a vertical plane? When is the end of the work in the same vertical plane as the axis of the cutter.

7. If a cutter is set central over the work before the table is swivelled, is it central after the table is swivelled? Give reason.

8. Is it easier to set the cutter central before or after the table is swivelled?

9. Why is it advisable to arrange the work, swivel the table, and feed the table laterally until it is about half an inch from the column before arranging and tightening the cutter on the arbor?

10. When laying out the lines of two adjacent teeth on the end of a spiral milling cutter blank, why are the lines rotated either 78° or 102°?

11. What is the difference between right-hand and left-hand spiral milling cutters?

12. Make a sketch similar to Fig. 242 to show the method of laying out a right-hand spiral milling cutter when using a milling machine with the head on the right-hand end of the table.

THE GRINDING MACHINE

CHAPTER XIV

GRINDING MACHINE CONSTRUCTION

228. Introduction.—A far greater advance in design, construction, and use, has taken place during the past few years in the grinding machine than in any other machine shop tool. Until recently the grinding machine was regarded as a tool-room machine, particularly useful only for finishing hardened steel. It is, however, now recognized as one of the most important machine tools for manufacturing purposes. This is owing to the remarkable development of the machine itself, and also of the abrasive wheels used, as the means of producing very accurate and beautifully finished surfaces, economically. The work may be any of the metals used in machine construction, such as cast iron, wrought iron, bronze; also hardened or unhardened steel of whatever variety.

Perhaps because of its comparatively rapid development, grinding is one of the operations least understood by the otherwise intelligent machinist, and this fact should be an added incentive for the ambitious beginner to gain as much knowledge as possible of the grinding machine, the characteristics of the various abrasive wheels, and the methods employed in grinding. Manufacturers are very willing to send catalogues of their machines to foremen or instructors for the purpose of placing them in the hands of those interested. Articles on this interesting subject are frequently published in the trade journals. It is recommended that the beginner obtain and read a catalogue or better still, an operator's manual and any other information he is able to get concerning the machine he is going to operate. He will thus acquire a

broader understanding of that particular machine and also a general knowledge, since the basic principles of the essential mechanisms are practically the same in all grinding machines of a given type. The young man who will study and reason, observe what others are doing, ask sensible questions and take advantage of every chance for experience will soon get the information he is after.

The function of the grinding machine is, like every other machine tool, the removal of metal by means of a suitable

FIG. 243.—A typical shop view of grinding machines. (*Courtesy Taft-Pierce Mfg. Co.*)

cutting tool. For the same reason that there are various types of lathes, milling machines, drilling machines, etc. there are various types of grinding machines. Just as there are different shapes and kinds of milling cutters for various purposes, there are several shapes and a variety of kinds of grinding wheels. In the construction of the grinding machine are used many mechanical features common in other machines —pulleys, gears, clutches, levers, cylindrical bearings, flat bearings, swivels, pawls, etc. These are all old acquaintances

doing their work in a different machine. It should not take long to learn how they operate in any grinding machine.

The cutting tool used is a grinding wheel or "abrasive" wheel, revolving at a high rate of speed. This wheel is made up of small sharp-edged fragments of a very hard substance cemented or "bonded" together. Very probably the boy in the shop as he sharpens a lathe tool or a drill in the "wet grinder" imagines that the wheel rubs off the steel. It may be that it does if the wheel is dull, that is, if the projecting edges have been rounded by continued grinding; but when the wheel is sharp it *cuts*. The chips are very small but they are real chips, nevertheless.

The tool grinder or wet grinder is a type of grinding machine of course, but when the name "grinding machine" is used a machine for grinding work and not tools is meant,—a machine with facilities for holding the work, various wheel speeds, with mechanisms for hand and power feeds; a real machine tool.

A few types of grinding machines are illustrated and briefly described in the following three or four pages. One standard machine is illustrated with the parts numbered and named.

Get acquainted with the machine you are running; learn the function of the various handwheels and levers, go back of the handles; find out what they operate. Adjust the feed for a given amount; study the feed mechanism. Learn how the stroke is adjusted for length and position and how it is reversed. Oil the machine carefully. As soon as convenient, learn how to adjust the wheel spindle bearings. Unless these bearings are properly adjusted poor grinding will result. It may be this machine you are running is all right but what about some other one? It is better to get information concerning elementary principles when you are recognized as a beginner.

The next thing is the cutting tool, the abrasive wheel. A few pages (beginning p. 322) are given to a brief catechism of abrasive wheels. Study this and anything else you can find on this fascinating subject.

And then study and practice to obtain the proper work speed, wheel speed, chip and feed, the right methods of grind-

ing cylinders, tapers, faces, holes, etc., etc. Most boys find that grinding is mighty interesting work.

Grinding machines are classified as to kind as Plain (Cylindrical), Internal, Surface (meaning plane surface) and Universal. Certain grinding machines are named according to the purpose for which they are made and here the term "grinder" may be used, for example, Cutter and Reamer Grinder and Drill Grinder. These two are toolroom machines and are

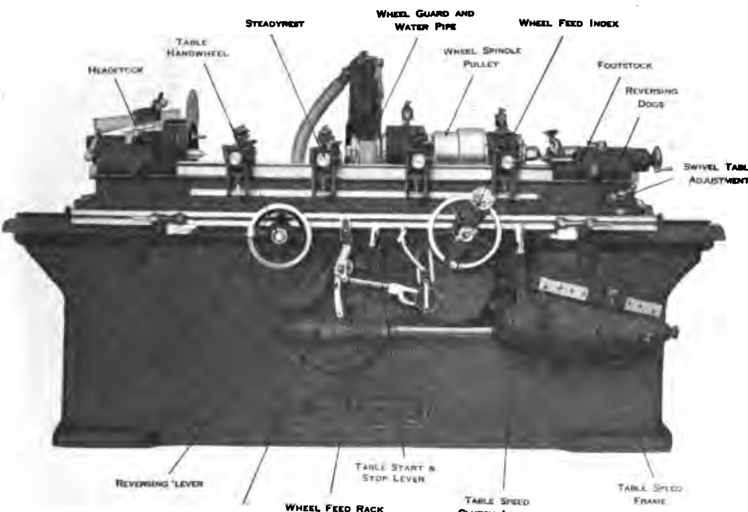


Fig. 244.—Plain grinding machine. (*Courtesy Norton Co.*)

standard equipment. Special manufacturing machines such as are used for grinding rolls, rings, car wheels, automobile engine cylinders, etc., are adaptations, more or less, of standard types, excepting perhaps the Heald Cylinder Grinding Machine (Fig. 251).

Grinding machines are classified as to size usually by number, but by some manufacturers according to the maximum size (diameter and length) of the work which the machines will accommodate.

FIG. 245.—Internal grinding machine. (*Courtesy Heald Machine Co.*)

FIG. 246.—Surface grinding machine with horizontal spindle. (*Courtesy Brown & Sharpe Mfg. Co.*)

229. The Plain Grinding Machine (Fig. 244).—A machine for grinding outside only, cylindrical or tapered work. Stock sizes range from 6 × 32 in. to 20 × 168 in. In commercial practice this machine has largely superseded the lathe for finishing cuts because accuracy is obtained easier, quicker and cheaper. In addition the same degree of accuracy and

FIG. 247.—Surface grinding machine with vertical spindle. (*Courtesy Pratt & Whitney Co.*)

economical production is obtained on hardened steel as on the softer metals, which fact has made possible the introduction of many heat-treated steel parts into machine construction that would outerwise have been impossible.

230. The Internal Grinding Machine (Fig. 245).—A machine for accurately finishing round holes of any size (within limits) either straight or taper, in such parts as gears,

bushings, cutters, gages, etc. (for "Internal Grinding Fixture" see p. 357).

231. The Surface Grinding Machine.—A machine for grinding flat surfaces. There are two distinct types of surface grinding machines, horizontal spindle, (Fig. 246) and vertical spindle (Fig. 247). Surface grinding machines are primarily

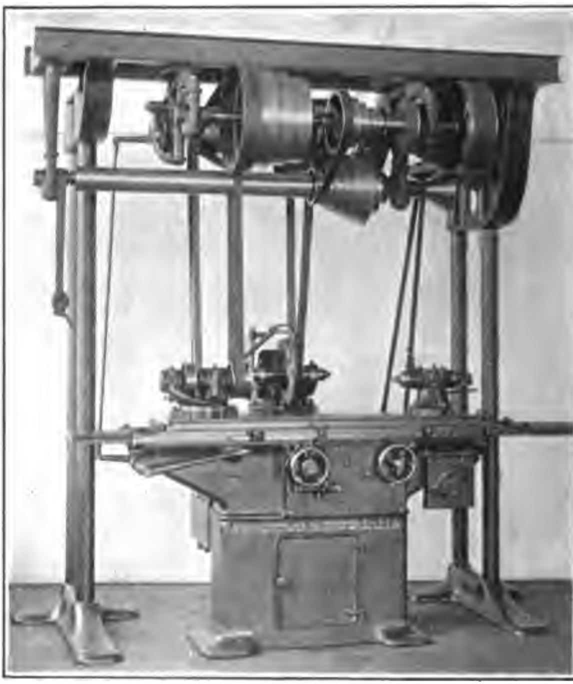


FIG. 248.—Universal grinding machine with direct-motor drive. (*Courtesy Brown & Sharpe Mfg. Co.*)

for the purpose of finishing pieces that have been previously roughed on the shaper or milling machine, but highduty vertical-spindle machines are manufactured that will efficiently finish flat surfaces of castings and drop forgings from the rough.

232. The Universal Grinding Machine (Figs. 248 and 249). This machine is provided with a swivel table and also with a swivel headstock and a swivel wheel head. These

features, in connection with certain attachments, permit of doing external and internal cylindrical grinding (straight or taper), surface grinding, face grinding, as on the sides of milling cutters, etc., and the backing off of reamers and cutters. It is a valuable machine for general machine shop and toolroom work.

233. The Cutter and Tool Grinding Machine (Fig. 250).—This machine together with its accessories and attachments is,

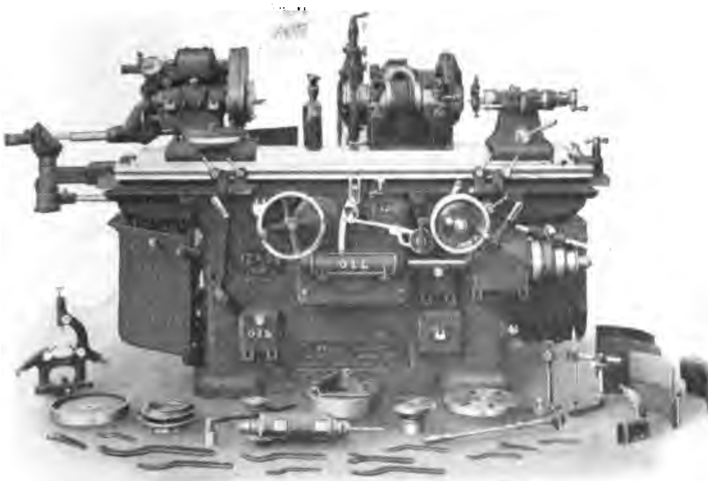


FIG. 249.—Universal (multipurpose) grinding machine. (*Courtesy Norton Co.*)

in effect, a small universal grinding machine, and is very useful for grinding small parts internally or externally. It is, however, specially designed to sharpen reamers, taps, and all kinds of milling cutters. The cutter grinding machine is a very necessary part of the equipment of a shop where milling machines are employed. Most manufacturers of this type of machine publish a booklet illustrating and describing the methods of sharpening reamers and milling cutters in their particular machine, and a careful study of the ingenious attachments of the machine at hand should prove helpful.

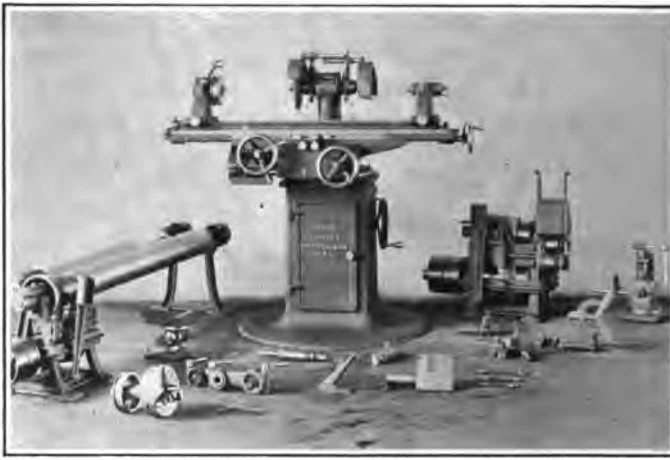


FIG. 250.—Cutter and reamer grinder together with the overhead works and a variety of attachments. (*Courtesy Norton Co.*)

FIG. 251.—Cylinder grinding machine. (*Courtesy Heald Machine Co.*)

234. Cylinder Grinding Machine (Heald) (Fig. 251).—An especially designed machine for the internal grinding of work that is of a shape or size that is inconvenient or impossible to rotate. The revolving wheel spindle is carried in a revolving head, the revolutions of one being entirely independent of the other. This revolving head consists of two eccentrics, one within the other with their relative positions adjustable, so that the *revolving* wheel spindle may be arranged to travel in a circular path similarly as a crankpin travels. The diameter of this circular path is changed by means of a worm and a worm wheel which permits of a very slight adjustment for the purpose of feeding, or of considerable adjustment if desired for any reason. The work table is provided with automatic feed in a direction parallel to the wheel spindle and with transverse adjustment. The knee which supports the work table has vertical adjustment.

235. Parts of the Universal Grinding Machine.—On the following pages is illustrated and described the Brown & Sharpe Universal Grinding Machine. Inasmuch as this machine embodies the fundamental principles of design and construction of machines of this class, it is believed that a study of these pages should prove helpful in acquiring knowledge of the names and purposes of the parts and the basic principles of the construction of any similar machine.

DESCRIPTIONS OF GRINDING MACHINE UNITS

The grinding machine illustrated in Fig. 252 is a universal grinding machine. Like the universal milling machine, it differs from the plain machine in that it has certain special swiveling features and a number of attachments which permit of a greater variety of operations. While the following brief descriptions apply particularly to the machine shown in Fig. 252 they apply also in general principles to the basic elements of the plain grinding machine.

236. The Bed.—To avoid every possible chance of vibration, the grinding machine must be rigid. Accordingly the bed, which supports the table the wheel stand and the feeding

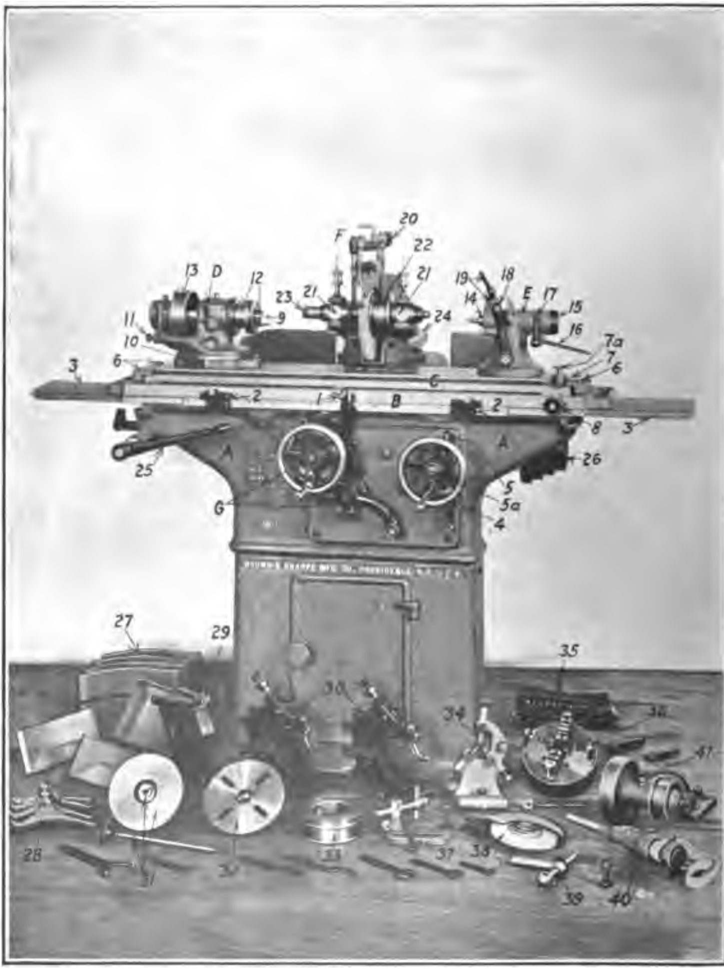


FIG. 252.—B. & S. universal grinding machine.

Parts of Grinding Machine

Unit Names

A. *Bed.*

B. *Sliding table.*

C. *Swivel table.*

D. *Headstock.*

E. *Tailstock.*

F. *Wheel head* (for detail see Fig. 255).

G. *Cross feed controlling mechanism* (for detail see Fig. 258).

H. *Overhead works.* See Figs. 259 and 248.

Part Names

1. *Table traverse reversing lever,* operates the mechanism which changes the direction of the movement of the table (either automatically by the reversing dogs (2) or by hand).

2. *Table reversing dogs* operate the reversing lever and determine the length of stroke. These dogs may be clamped in any position in a rack on the table, and have provision for considerable adjustment after clamping.

3. *Bed guard* to keep water and dirt from the bearing surfaces.

4. *Handwheel* for table traverse.

5. *Control* for power feed of table. The control is sometimes a knob at 5*a*.

6. *Swivel table clamping screws,* at both ends of table

7. *Graduated scale for showing position of swivel table,* and 7*a*, *swivel table locking pin.*

8. *Swivel table adjusting knob.* First loosen clamping screws (6) and perhaps adjust locking pin 7*a*, then turn knob until the desired position of swivel table is indicated on graduated scale (7).

9. *Headstock center.*

10. *Headstock index pointer* indicates on graduated base the angular position of the headstock center with reference to the center line of the swivel plate.

11. *Live spindle locking pin* for locking headstock spindle when grinding work on dead centers.

12. *Dead center pulley* and *work driver* for driving work held on dead centers.

13. *Live spindle driving pulley* for driving headstock spindle when using chuck.

14. *Tailstock spindle.* The tailstock spindle is backed up by spring tension to overcome any tendency of vibration of the work and to take care of the expansion in the length of the work which may be caused by the heat of grinding.

15. *Tailstock spring guard.*

16. *Center with-drawing lever* for withdrawing the center when putting in or removing the work.

17. *Tailstock spindle clamping lever.*

18. *Clamping lever* for clamping the tailstock to the table.

19. *Diamond-tool holder bracket* for clamping the diamond tool holder (39) when truing the wheel. The diamond tool is clamped in the holder.

20. *Water piping.* The spout should be very close to the work and not over a quarter of an inch from the wheel.

21. *Grinding wheel spindle boxes.*

22. *Wheel driving pulley and sleeve.*

23. *Guard for end of spindle.* This end of the spindle is tapered, provided with a key and threaded to receive the off-set wheel sleeve (38).

24. *Wheel stand* (see Fig. 255).

25. *Starting* and *starting lever,* operates clutch in overhead works which permits of starting or stopping the work and automatic feeds without stopping the motor.

26. *Table feed mechanism cone pulley.*

Accessories

27. *Table splash guards.*

28. *Table splash guard brackets*

29. *Plain back rest.*

30. *Universal back rests.*

31. *Face chuck, chuck plate and bushing,* also *face chuck draw-in rod* for holding slotting cutters and similar pieces, when grinding to thickness.

32. *Face plate.*

33. *Large dead center pulley.*

34. *Center rest.*

35. *Work dogs and dog tray.*

36. *Four jaw chuck.*

37. *Tooth rest* used when sharpening cutters.

38. *Off-set grinding wheel, wheel sleeve and wheel guard.*

39. *Diamond tool holder.*

40. *Internal grinding fixture.*

41. *Internal grinding fixture countershaft.*

mechanisms, is designed to give great strength and rigidity. The hearing surfaces (ways) for the sliding table are especially large (long and wide) and are very accurately machined and scraped. The rear top surface of the bed supports the wheel stand and is accurately machined, especially in relation to the table bearing surfaces in order that the center line of the wheel spindle shall be in exactly the same horizontal plane as center line of the work. The bed is supported on a base of box form braced internally.

237. The sliding table is deep and strongly ribbed to retain its shape permanently. In operation this table slides back and forth on the bed and is consequently provided with bearing surfaces just as accurately made as the ways on the bed. To protect the ways extensions are provided on each end of the sliding table. A suitable portion of the top of the sliding table is machined to provide a seat for the swivel table.

238. The swivel table is pivoted on a large stud located in the center of the sliding table and may be swivelled any amount up to seven or eight degrees in either direction from its normal position of parallel to the ways. This is for the purpose of grinding tapered work. Clamps are provided at both ends of the table. For the convenience of the operator when setting the table for a taper (or when setting it back to straight) graduations are provided (7), Fig. 252. These graduations are for an *approximate* setting only. Never rely altogether on the swivel graduations when accuracy is desired. A T-slot is provided in the swivel table for the purpose of bolting the headstock and the tailstock.

239. The Table Feeding Mechanisms.—When the grinding machine is running and the control (5), Fig. 252, is moved to engage the clutch, the table starts to feed, and will feed in the one direction until one of the dogs (2), pushes the table traverse reversing lever (1), which operates a bevel gear reversing mechanism and changes the direction of the table feed.

The table feeding mechanism and the reversing mechanism while fairly complicated for the beginner are ingenious and

therefore interesting. The sketches, Figs. 253 and 254, have been made merely to illustrate the principles of these mechanisms.

Motion is transmitted from the overhead works to the cone pulley, Fig. 253, thence through the reducing gears G_1 G_2, G_3 to the clutch shaft S_1 to which is feathered the sliding clutch member C_1. The position of C_1 in gear G_4 or G_5 gives

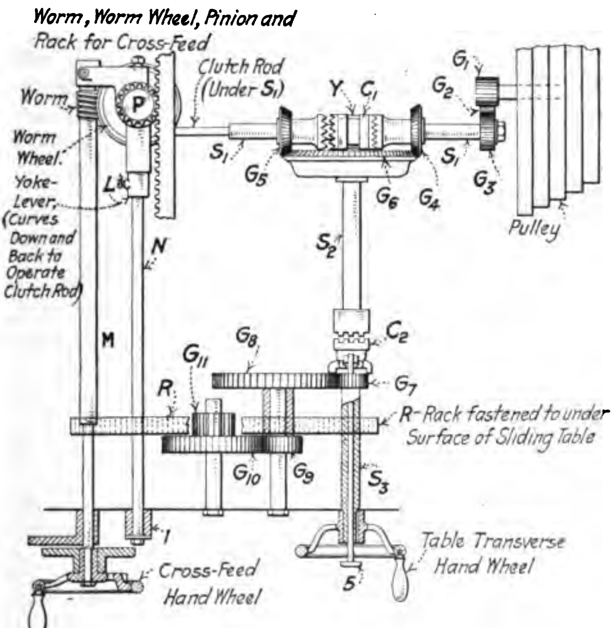


Fig. 253.—Table feeding mechanism of grinding machine, also shows the worm, wormwheel, pinion and rack for the cross feed.

motion to and determines the direction of rotation of gear G_6 (bevel gear reverse see par. 151). Motion of G_6 is transmitted through the shaft S_2 and (when the clutch C_2 is in) to the gear G_7 on the table feed hand wheel shaft S_3, thence through the quill gears G_8 and G_9 to the rack pinion sleeve gear G_{10} and the rack pinion G_{11}. The pinion G_{11} meshes with the rack R which is fastened to the under surface of the

sliding table. Of course, reversing the direction of gear G_6 reverses the direction of all the gears that follow, also the direction of the rack and consequently the table.

240. The Table Feed Reverse (Fig. 254).—The clutch member C_1 is moved to engage either gear G_4 or G_5 by the yoke Y which is fastened to the clutch rod R (for C_1, Y, G_4 and G_5, see also Fig. 253). The quick snappy action of the clutch rod (and yoke) necessary to throw the clutch C_1 instantly to reverse the direction of the table is due to the force of springs K_1 and K_2 (one for each direction). The increased

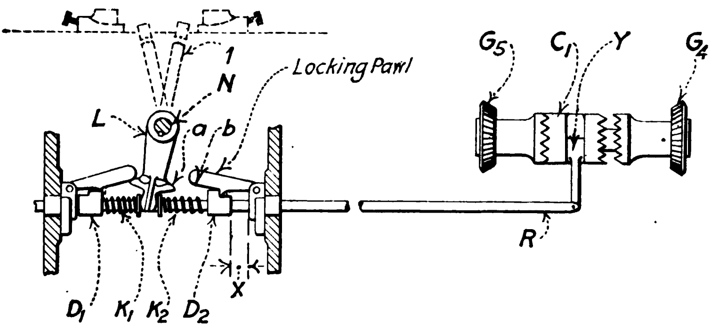


FIG. 254.—Table feed reversing mechanism.

compression and the release of the springs is obtained by means of a lever yoke L at the rear of the shaft N Fig. 253 to which shaft is fastened the table traverse reversing lever (1). In fact the lever yoke L for compressing the springs is also fastened to the shaft N as shown in Fig. 253, and curves down under the wormwheel to reach the clutch rod.

The dogs D_1 and D_2 (Fig. 254) are fastened to the clutch rod and the springs K_1 and K_2 are coiled around the rod and are separated by the lever yoke L the end of which forms a yoke over the rod.

As shown in the sketch, the clutch member C_1 is engaged with gear G_5 and held by a locking pawl engaging D_2. As the reversing dog comes in contact with and pushes the reversing lever (1), the lever yoke L on the other end of the

reversing shaft N moves to the right and compresses the spring K_2 until point a of the lever L lifts point b of the locking pawl and releases D_2. The force of the compressed spring thus released pushes D_2 and also the rod, the yoke, and consequently the clutch which snaps into engagement with gear G_4 thus instantly reversing the direction of the table.

241. The Headstock.—(In the following paragraph part numbers noted refer to Fig. 252).

Most grinding machine work is supported on centers (headstock and tailstock) although in the universal grinding machines provision is made to hold work in other ways as will presently be explained. It will be remembered that in lathe work if the live center runs out ever so little the cylindrical surface of the work turned will not be concentric with the centers. To obviate any chance of error of this kind the work to be ground on centers is revolved on two "dead centers;" the headstock center as well as the tailstock center remaining stationary. The work is driven by a loose pulley the bearing of which screws on the threaded nose of the spindle. The work driving dog (35) is driven by a pin which projects from the pulley. The spindle is held stationary by the stop pin (11).

When it is desired to hold work in the four jaw chuck (36) or on the face plate (32) or on the face chuck (31) the loose pulley is removed by unscrewing from the spindle, and the work holding device selected is screwed on the spindle. To revolve the work it will be necessary to arrange the suitable belt from the drum overhead to the spindle driving pulley (13) and withdraw the stop pin (11) from the pulley.

The universal grinding machine headstock has swivel construction being pivoted on the base. Graduations in degrees indicate the position of the head. This swivel feature is useful for grinding angles and for face grinding etc. (see Figs. 270 and 272).

The face chuck (31) as used in connection with its expansion bushing, tapered-head screw, and draw-in rod, is especially useful for grinding the sides of slotting cutters or

any similar piece having a hole. The head is swivelled about 90° and then adjusted carefully to give the slight concave surface (clearance) desired on the cutter or to exactly 90° to give a flat surface on a disk or similar piece. A section view of the face chuck and a typical set-up is shown on page 356.

242. The tailstock is illustrated in *E*, Fig. 252. It is clamped in the desired position on the table by means of a lever (18) and is aligned as is the headstock, by the tongue which fits in the table T-slot.

NOTE.—Do not depend on this alignment for extreme accuracy. For example, if it is necessary to change the position of the tailstock to accommodate shorter or longer work, the change may cause a slight error in the alignment of the centers.

The movement of the tailstock spindle to put in or remove the work is not obtained by means of a screw as in the lathe or milling machine. The adjustment of the work between centers is according to the force of a spring tending to push the tailstock spindle (and center) forward. The advantages of this construction are that the tendency of vibration is largely overcome, and, as the work expands due to the heat generated in grinding the center yields a sufficient amount. If the work is of such a size that its weight would tend to force the center back, the spindle may be clamped rigidly.

A bracket (19) is provided for receiving and clamping the diamond tool holder (39).

243. The wheel head is shown at *F*, Fig. 252 and a side view is illustrated in Fig. 255.

The grinding wheel is the cutting tool and the wheel head supports the wheel. The relative positions of the parts of the wheel head (24 and 24*A*-*B*-*C*) determine the position of the wheel and the direction of the wheel feed.

The wheel is mounted between suitable flanges[1] on a hardened and ground spindle which runs in bronze bearings. The bearing boxes are inserted in bushings which fit in the arms of the wheel stand and are held in place by caps. When

[1] For mounting grinding wheel see p. 331.

necessary to change the wheel, the wheel guard is removed, the caps which hold the bearings in place are loosened, and the wheel, spindle, and bearings are taken out and the change of wheels made. When putting the wheel spindle and bearings back in the wheel stand, care must be taken to have all parts clean and the bearing bushings in the correct position, (oil hole up). Turn the wheel slowly by hand while first one cap and then the other is screwed down tight.

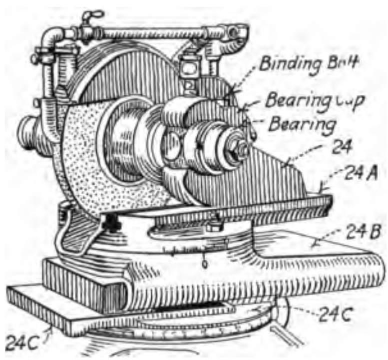


Fig. 255.—Grinding machine wheel head. The *wheel stand* (24) may be clamped in the desired position on the *wheel stand platen* (24*A*). The platen may be swivelled on the *wheel stand slide* (24*B*). The wheel stand slide bearings are very accurately scraped to fit similarly finished surfaces on the *wheel stand slide bed* (24*C*) and the movement of the slide (24*B*) on the bed (24*C*) gives the cross feed of the wheel. The bed is pivoted and may be swivelled and clamped in an angular position for the purpose of grinding abrupt tapers or angles. See Fig. 257.

244. Cross Feed Mechanism.—The movement of the slide, 24*B*, Fig. 255 gives the cross feed of the wheel. The feed mechanism is illustrated in Fig. 256. A movement of the cross feed handwheel operates, through the shaft M, a worm W and wormwheel W_2 to give motion to the pinion P which engages a rack R fastened to the wheel stand slide. A plan view of the worm, wormwheel, pinion and rack is shown in Fig. 253.

The wheel stand slide bed is so constructed that it may be swivelled for the purpose of grinding steep tapers and angles.

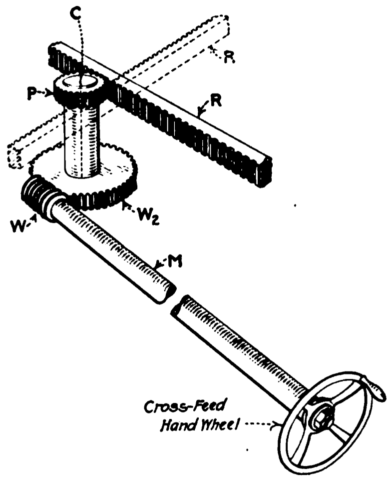


FIG. 256.—Sketch to illustrate the relative positions of the cross feed hand wheel, the shaft *M*, worm *W*, worm wheel, W_2 the pinion *P*, and the rack *R* which is fastened to the wheel stand slide. Particular attention is called to the fact that the axis of the wormwheel and the pinion is in the pivot center of the wheel stand slide and consequently by turning the hand wheel, the rack (and the wheel stand slide) is moved (fed) no matter what its angular position on the bed may be.

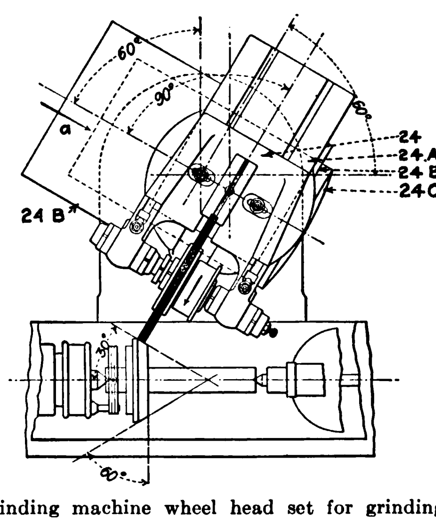


FIG. 257.—Grinding machine wheel head set for grinding tapered work. Part numbers are same as shown in Fig. 255.

The feed pinion for the slide is in the pivot center of the slide bed (*C*, Fig. 256) consequently when the cross feed handwheel is turned, the wheel is fed along the work in the direction determined by the setting of the wheel stand slide bed.

In Fig. 257 is illustrated a typical setting for grinding at an angle. It will be observed that the wheel stand bed 24*C* is swivelled 60° carrying with it the wheel stand slide 24*B*. This will cause the cross feed to operate at an angle of 30° with the center line of the work (arrow *a* shows direction of feed). In order to bring the face of the wheel parallel to the surface to be ground, the wheel stand platen 24*A*, carrying the wheel stand 24, is swivelled 90° on the slide. As the cross feed handwheel is turned the wheel feeds across the angular surface of the work. To take a deeper cut, it is necessary to move the table traverse handwheel a trifle.

The alignments of the wheel spindle and its supporting parts are such that no matter what cross slide swivelling or sliding adjustments are made, the axis of the work will be in a horizontal plane in line with the headstock and tailstock centers. That is, no matter what shape or size of work is being ground, the cutting tool (wheel) is always "on center."

245. The Automatic Wheel Head Cross Feed.—Commercial grinding machines, internal, cylindrical, plain or universal are equipped with automatic wheel head cross feed, operated by a ratchet and pawl mechanism. Also for the purpose of still greater efficiency, ingenious devices, either electrically or mechanically controlled, are provided by the different manufacturers for stopping the feed when the diameter of the work has been ground to the given size. It is, of course, necessary to adjust the cross feed stop when setting the machine, either to the first piece when ground to size, or to a sample, and in the mechanically controlled mechanism it is necessary to occasionally make a further slight adjustment to compensate for the wear of the wheel. Following is a description of the cross feed mechanism as applied to Brown and Sharpe grinding machines and the automatic stop which operates mechanically.

Brown and Sharpe Automatic Cross Feed (Fig 258).—This consists of a ratchet wheel (6) fastened to a shaft shown at *M*, Fig. 256 that controls the transverse movement of the grinding wheel slide. A pawl (5) actuated through levers (3 and 4) by dogs (2) at both ends of the sliding table traverse, operates the ratchet wheel and automatically draws the wheel

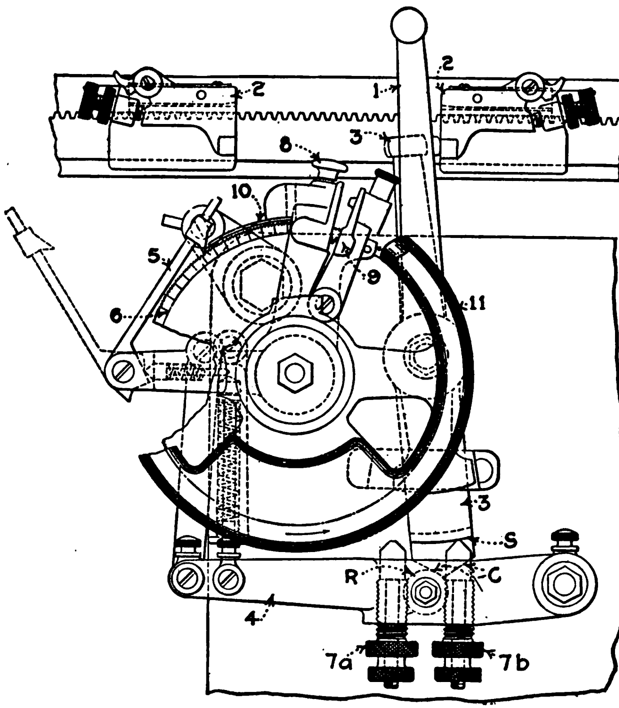


Fig. 258.—Cross feed controlling mechanism. 1. *Table reversing lever.* 2, *Table reversing dogs.* 3, *Auxiliary lever* is moved by the reversing dogs the same time the reversing lever is moved and operates the feed lever. 4, *Feed lever* which operates the pawl. 5, *Pawl*—the amount of movement of the pawl on the ratchet wheel determines the amount of cross feed. The distance the pawl moves is controlled by the positions of the adjusting screws. 6, *Ratchet wheel.* 7, *Adjusting screws.* 8, *Holding latch.* 9, *Changing latch.* 10, *Throw-out shield* for automatically stopping the feed. 11, *Hand wheel.*

slide in at each table reversal. The pawl continues to operate the ratchet wheel until a shield (10), fastened to an arm that

revolves with the ratchet wheel, prevents it from further engaging the ratchet teeth. The cross feed is therefore automatically thrown out when this point is reached. For any considerable movement of the shield lift the latch (8).

The ratchet wheel is graduated and each tooth is equal to a movement of the wheel slide of one-eighth of a thousandth of an inch, or a reduction in diameter of the piece being ground of one-quarter of a thousandth of an inch. It is not necessary, however, to look at these graduations in setting the shield for light cuts so that any given number of thousandths will be removed from the piece. The arrangement provided for this purpose, consists of a latch-like mechanism (9) that is pinched between the thumb and the forefinger, and each time it is pinched the shield (10) moves back one tooth on the ratchet wheel. So, if it is required to remove a given amount, the grinding wheel is drawn in by means of the handwheel until it just trues up a place on the work. The diameter is carefully measured at this point and then, for example, if there are two thousandths more to come off, the latch is pinched four times for each thousandth to be removed, or eight times for the two thousandths; the machine will then grind exactly two thousandths from the piece. Succeeding pieces can be ground to the same diameter without changing the adjustment of the mechanism, except to compensate for the wear of the wheel.

Before a new piece of work is put in, the wheel slide is moved back by simply throwing the pawl out of engagement and turning the handwheel. After the new piece is carefully set in place start it revolving, the wheel slide is then moved up until the wheel just touches the work, the pawl is thrown into action, and the table traverse started. When the pawl reaches the shield the cross feed will be thrown out and the piece will be the same diameter as the previous one. As the wheel wears, a slight adjustment of the slide can be made by means of the latch to compensate for the difference in the diameter of the work.

The feed operates only at the very ends of the table traverse

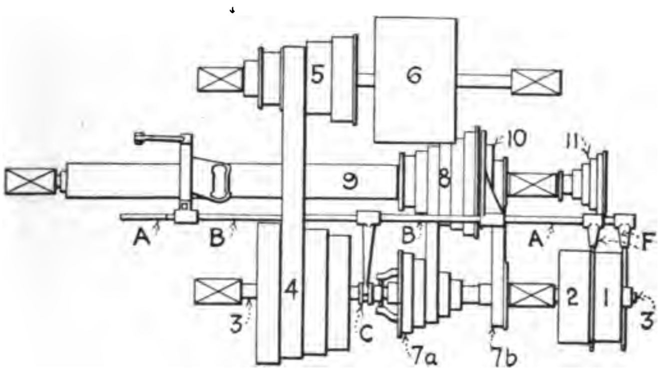
and the amount fed at either end is independent of that fed at the opposite end. For instance .003 in. can be fed at each reversal on one end while .001 in. is fed at each reversal on the other end.

To Change the Amount of Cross Feed.—The greater the movement of the lever (4), Fig. 258 the greater the feed, because the lever carries the pawl (5). The auxillary lever (3) operates at the reversal of the table and through the action of the cam (bevelled surfaces *C*) on the roll *R* serves to move the lever (4) down against the force of a spring. The ends of the adjusting screws *7a* and *7b* bear in turn against the shouldered surface *S* on the lever (3) and act as stops against the upward (spring tension) movement of (4). The positions of *7a* and *7b* therefore determine the amount of feed at each reversal, the farther either screw is turned in, the less the feed at the corresponding reversal of the table.

246. The Overhead Works (Fig. 259).—The machine is started by moving the shipper *S* which moves the shipper rod *A* and the fork *F* thus shifting the driving belt from the loose pulley (1) to the tight pulley (2). Motion is transmitted through the shaft (3) to the wheel driving cone pulley (4) to the second wheel driving cone pulley (5) to the wheel driving pulley (6) thence to the wheel sleeve and wheel. There are four steps on the pulleys (4 and 5) hence there are four wheel speeds available.

The movement (revolutions) of the work and also the feed movements (table traverse and automatic cross feed) are controlled independently of the wheel speeds. That is, the double-cone pulley (*7a* and *7b*) runs freely on the overhead works driving shaft (3) except when the clutch *C* is engaged. This clutch is controlled by the stop lever (25), Fig. 252, working through a connecting rod *P* and a bell crank lever *L* to the clutch operating rod *B*. When the clutch is engaged, motion to the head stock (and work) is given through the cone pulleys (*7a*) and (8) and the "work drum" (9). There are six steps on the pulleys (*7a*) and (8) consequently there are six work speeds entirely independent of the wheel speed.

To operate the table traverse and the cross feed mechanism, notion is given the cone pulley (26), Fig. 252. This motion s transmitted from the cone (7*b*) to the cones (10) and (11) he latter two being fastened to a sleeve. There are five teps on the cone pulley (11) giving five speeds and five more



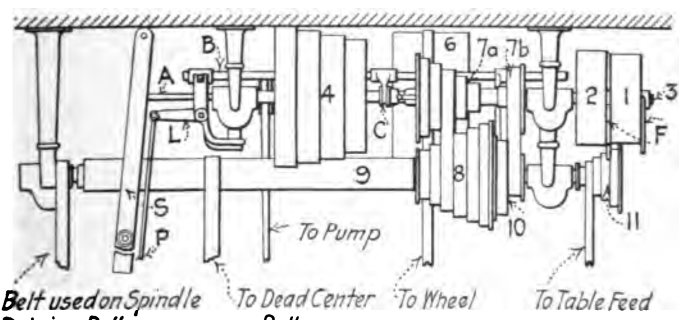


Fig. 259.—Overhead works. Views are looking from the top and from the front.

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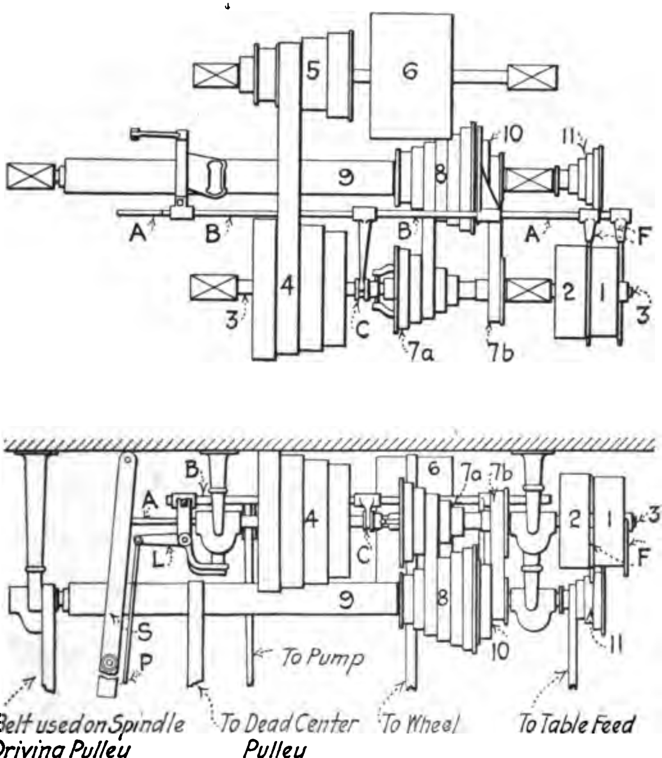

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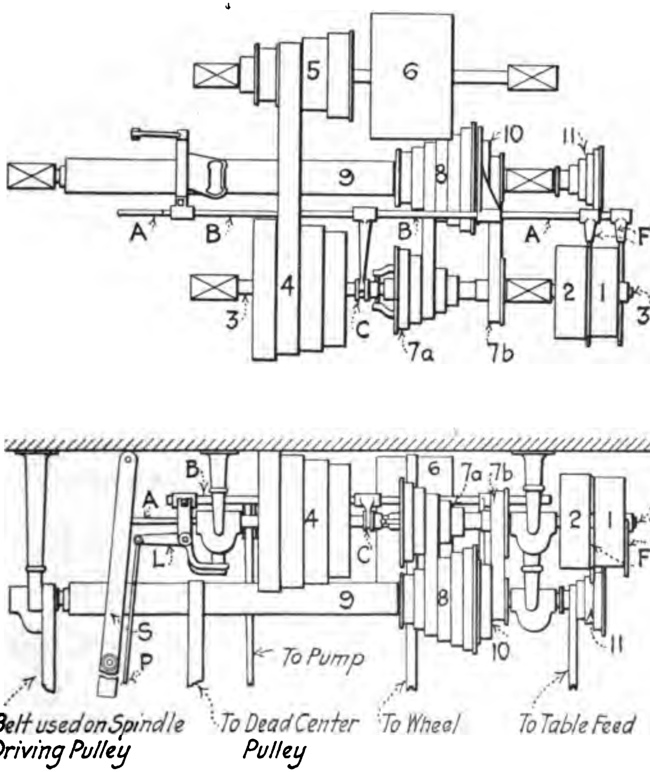

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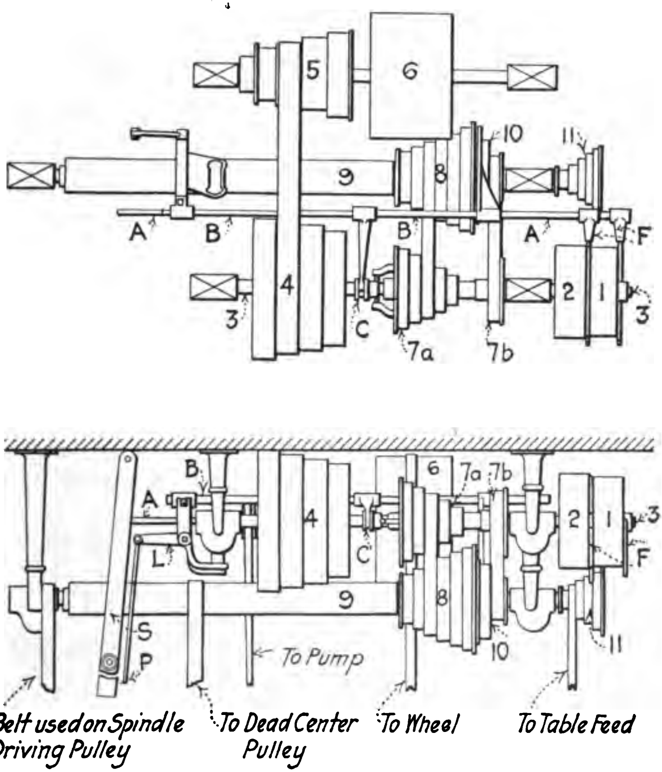

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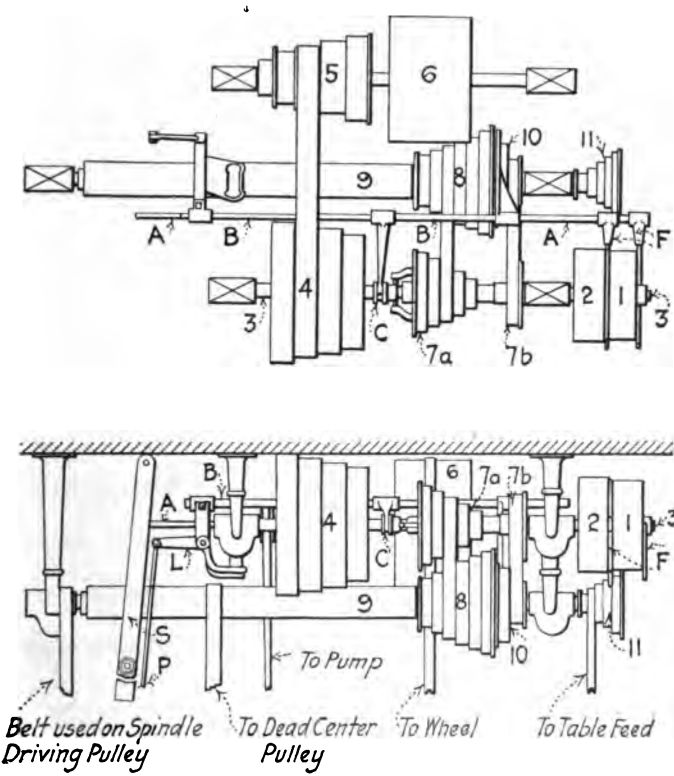


Fig. 259.—Overhead works. Views are looking from the top and from the front.

speeds are available by changing the belt to the other steps of the cone pulleys (7*b*) and (10) giving a total of ten table traverse speeds (or table feeds).

It will be noted that by disengaging the clutch *C*, the work and also the table traverse is stopped without stopping the

wheel. This serves the double purpose of saving time and keeping the wheel bearings at a uniform temperature. The latter is necessary in accurate grinding. It may be said that after a wheel has been running a few minutes, it sort of adjusts itself. In other words, a wheel in cold bearings will not "size" the work the same as if the bearings are warm.

Questions on Grinding Machine Construction

1. Move the sliding table by hand. How does turning the handwheel serve to move the table?

2. What similarity of construction do you notice in the mechanism for moving, by hand, the table of the grinding machine and the carriage of the lathe?

3. In the power drive for the table there are several pairs of "reducing gears." What is the object of having one of the gears in each pair smaller than the other?

4. Compare the power drive of the grinding machine table to the drive of the planer·platen. In what respects are they similar.

5. What mechanism is used to reverse the movement of the grinding machine table?

6. How does turning a hand wheel serve to operate the cross feed of the grinding wheel?

7. Explain why the cross feed pinion is in the swivel center of the wheel stand slide bed.

8. How does the cross feed mechanism in the grinding machine differ from the cross feed mechanism in a lathe?

9. Why not have the cross feed in a universal grinding machine operate by a screw?

10. Why is it possible to do *more* work in a machine having automatic feed.

11. Why does automatic feed make for *better* work?

12. Do you know how to make the adjustment to feed the desired amount at each end of stroke?

13. How is the automatic feed stop set?

14. There are two pulleys on the headstock, one keyed to the spindle the other running freely. Explain the purpose of these pulleys.

15. What is the purpose of the stop pin in the headstock?

16. Why is the head stock made so it can be swivelled?

17. What is the reason for the spring in the tailstock?

18. How is the diamond held when truing the wheel?

19. How is the tailstock moved on the table? Is perfect alignment maintained if the tailstock is moved?

20. How is the grinding machine table swivelled?

21. How many wheel speeds has the machine you are studying?

22. How many work speeds has this machine?

23. Explain how you are able to stop the work without stopping the wheel. Why is this an advantage?

24. What is the purpose of the long pulley(work drum) in the over head works?

25. Sometimes the belt from the drum to the headstock is unduly stretched. How does this happen?

26. What is a *plain* grinding machine? A *universal* grinding machine?

27. Are there any other grinding machines in the shop, if so what are they called to differentiate them?

28. State at least three reasons why the grinding machine is an indispensible tool.

CHAPTER XV

GRINDING WHEELS

247. Introduction.—Success in grinding depends more upon the knowledge the operator has of the characteristics, and particularly the action under different conditions, of the grinding wheel, than upon anything else. It is an interesting study and the more deeply one gets into it the more interesting it becomes. Grinding is really in its infancy, and offers to the young machinist who aspires to be a production engineer one of the most fascinating and worth-while studies in the field of machine work.

The manufacturers of grinding machines and grinding wheels have for years consistently worked for the good of the man in the shop. Their literature is a mine of useful up to date information.

The following "catechism" is merely a starter in the right direction.

Before proceeding to a study of this catechism it may be well to get a general idea of the features of an abrasive wheel. Take any grinding wheel and examine it, preferably with a magnifying glass if one is at hand. It will be observed that the wheel is made up of a great many particles of grit bonded together. The size of the particles (the "grain") determines the coarseness or fineness of the wheel, similarly as the size of the teeth determine the coarseness or fineness of a file.

It will be observed further that the particles of grit have sharp projecting edges and points. These are the cutting edges and the abrasive material is hard enough to cut hardened steel and tough enough to stand up and not fracture under the cutting pressure. However, the little cutting points and edges do become dull after a time and to "keep the wheel

sharp" it is necessary that the dull particles be removed to allow the sharp particles underneath to appear and do the cutting. As in any other cutting tool, so in the grinding wheel the duller the edge the more pressure required to cut. The ideal wheel would automatically sharpen, that is when the cutting edges were too dull to do efficient work on the given material, the excessive pressure of the cut would serve to break away the dull particles. The different grinding jobs offer variable conditions of cutting pressure, etc., and consequently abrasive wheels are made in a variety of "grades" meaning that the particles of abrasive are more firmly held together in some wheels than in others. The wheel which retains its particles with the greatest tenacity is called *hard* and the wheel from which the particles are easily removed is called *soft.*

The tendency of most machinists is to use a wheel that is too hard. "Use a Soft Wheel" is almost as important a slogan in grinding as "Keep Cutters Sharp" is in milling. To be sure a soft wheel does wear away more rapidly, but is it not wiser to wear out a $3 wheel earning $100 than to save part of the wheel and earn only $50 in the same length of time?

A SHORT CATECHISM ON GRINDING WHEELS

248. Abrasives and Bonds.

What Is an Abrasive?—An abrasive is an extremely hard, and more or less tough substance, which when fractured, has the formation of many sharp cutting edges and corners. Some of the abrasives used in shop practice, such as sandstone, emery, and corundum, are natural products, while others, for example carborundum, alundum, crystolon, and aloxite, are artificial products.

What Is an Abrasive Wheel?—Small particles or grains of abrasive are held together by various cements or bonds, in hundreds of shapes and sizes of wheels. The action of the abrasive or grinding wheel, mounted on the spindle of the grinding machine, and revolving at a high rate of speed, is to

bring a countless number of cutting points and edges in contact with the metal to be removed. An abrasive wheel is a *cutting tool.*

What Is Sandstone?—The old fashioned "grindstone" is an abrasive wheel made of sand stone which is a rock consisting of sand, more or less firmly united by some cement such as silica, iron oxide, or calcium carbonate. Sandstone, being comparatively softer than the more modern abrasives, the grindstone has been almost entirely superceded by the more efficient grinding wheels.

What Is Emery?—Emery is a natural product consisting of from 50% to 60% crystalline aluminum oxide[1] which gives it the valuable properties of hardness and toughness essential to an abrasive. The other principle substance in emery is iron oxide, which gives it the dark color.

What Is Corundum?—Corundum is similar to emery, but has a much larger percentage (about 75% to 90%) of crystalline aluminum oxide. It is, therefore, harder than emery and somewhat lighter in color. The best corundum is found in Canada.

What Is Alundum?—Alundum is an artificial corundum made by Norton Co., Worcester, Mass. It is the trade name for an oxide of alumina, manufactured by fusing the mineral bauxite (a very pure form of aluminum oxide) in an electric furnace, which transforms (crystalizes) the clay-like substance bauxite into one of the hardest abrasives known. The manufacture of alundum can be controlled to the extent of obtaining an abrasive of known "temper," that is, different combinations of hardness and brittleness, adapted to various classes of grinding can be produced.

What is Carborundum?—Carborundum (Carborundum Co.,

[1] Aluminum oxide (alumina) forms the basis of many rocks and soils. In its uncrystalized form it is a soft white powder, when crystalized it is one of the hardest substances known. Some of the most valuable of the precious stones, for example the ruby and emerald, are nearly pure crystalized alumina. Emery and corundum may be compared to a crystalized sponge with the intersticies filled with impurities. They are hard in proportion to their content of crystalized aluminum oxide.

Niagara Falls, N. Y.) is a trade name for carbide of silicon. It is manufactured abrasive, and the crystaline formation of the two elements, carbon and silicon, is accomplished by subjecting a mixture of coke and sand to a heat of 7000°F. in an electric furnace. Carborundum crystals are hard and sharp and combine the valuable proportion of toughness and hardness to a very remarkable degree. It is recommended as very satisfactory for grinding work in general and especially for grinding cast iron.

What Is Crystolon?—Crystolon is the trade name given by the makers, Norton Co., to their carbide of silicon abrasive. It is made from a mixture of coke, sand, sawdust, and salt subjected to a very high temperature in an electric furnace. It is carbide of silicon similar to carborundum and has the same general properties.

What Is Aloxite?—Aloxite (Carborundum Company) is the name given to an abrasive that is especially valuable in the grinding of steel. It is made in an electric smelting furnace from the proper mixture of an aluminum oxide and coke to furnish a nearly pure alumina. It is exceedingly tough in addition to having the essential properties of hardness and sharpness.

What Are the Advantages, if Any, of Artificial Abrasives?—Artificial abrasives were originally made because a uniform high quality of emery, most of which came from Greece and Turkey, or of Canadian corundum could not be obtained in sufficient quantities. Constant improvement in methods and means of manufacturing abrasives has taken place with the result that artificial abrasives may now be obtained suitable for the given purpose, that is, of the proper "temper" (combination of hardness and toughness desired) cheaper than the natural abrasives.

Many experienced polishers prefer the natural abrasives, emery and corundum, for making up their wheels, claiming that they hold better in the glue and thus give longer wear and a better finish.

Likewise, many experienced grinding machine operators prefer corundum wheels, especially for finishing hardened steel,

because the grains are just brittle enough to break when they become dulled and thus present new cutting edges to the work. Such a wheel cuts fast and cool and gives a beautiful finish.

How Are the Particles of Abrasive Classified as to Size?—After the abrasive is cleaned from dirt and other impurities it is crushed beneath a series of rolls and screened through sieves of different meshes. The size of the particular particles is designated as *grain*, according to the meshes per linear inch of the finest screen through which they will pass, as 36 grain, 46 grain, 60 grain, etc.

What Is the Bond?—The "bonds" used in the manufacture of abrasive wheels are the adhesive substances such as suitable clays, silicate of soda, shellac, rubber, and celluloid, which when fused, baked or prepared otherwise as the case may be, serve to hold the grains of the abrasive more or less firmly together. The character of the bond determines the *kind* of wheel as will presently be explained and the way in which the given bond is treated in the making of the wheel determines the *grade* of that wheel.

249. Classification of Grinding Wheels.

What kinds of wheels, according to the process of manufacturing are mostly used? Vitrified, silicate, and elastic wheels.

What are vitrified wheels? A large proportion of grinding wheels are made by the vitrified process. Suitable clays and fluxes are mixed with the abrasive, enough water is added to give the desired consistency (like mud) and the whole stirred in power driven kettles. It is then drawn off into forming rings (molds) and allowed to set. When sufficiently dry the "wheels" are turned to approximately the shape and size required. They are then taken to the kilns where they are subjected to a uniform temperature of nearly 3000°F. for 100 hours or more, which causes the clay to partially melt or vitrify. A week or more is allowed for the gradual cooling of the kiln, and as the fused clay cools, it crystallizes and binds the grains of the abrasive firmly together. Moreover as the wheel cools, the bond has the tendency to separate a little, producing a porous

wheel, which has certain advantages of free cutting, but has the disadvantage of no elasticity. Thin vitrified wheels break so easily as to be impractical.

What Are Silicate Wheels?—Silicate or semi-vitrified wheels are usually made with silicate of soda as a bond. After the abrasive and the bond are thoroughly mixed, it is very carefully tamped in molds by skilful molders. Very hard wheels and the thinner wheels made by this process are molded under hydraulic pressure. After molding, the wheels are baked in ovens. A much lower heat for a much shorter time than in the case of the vitrified wheels causes a chemical reaction which hardens and sets the bond.

What Are Elastic Wheels?—Shellac is the bond mostly used in making the elastic wheels, although rubber, vulcanite, and celluloid are sometimes used. The proper mixture of the bond and abrasive is tamped or rolled or forced by hydraulic pressure into molds. The wheels are then baked at a low heat to set the bond. Very thin wheels of great comparative strength can be made by this process. Such wheels are used for sharpening saws, cutting off stock, etc.

What, Theoretically, Is a Perfect Grinding Wheel?—A wheel made of hard sharp grains of the most durable abrasive for the metal to be ground, so bonded that when the cutting points become dulled they will break away, automatically, so to speak, from the surface of the wheel, and allow the sharp points that are below to come into action.

How Is This Condition Approached in Practice?—By the use of an abrasive of extreme hardness, combined with a temper neither too tough nor too brittle, and the employment of a bond of a sufficient strength to give the desired holding properties. The bond of a wheel not only holds together the grains of abrasive but the amount of the bond and its character determine how strongly the particles are held together.

How Are Wheels Classified as to Their Hardness?—Wheels are classified as to their hardness by *grade*. Wheels from which the abrasive is more readily broken during operation are known as soft grade and those that strongly retain the abrasive

grains are called hard grade. The degree of hardness or softness is designated by letters or numbers. It is to be regretted that no two manufacturers are alike in the grading of their product.

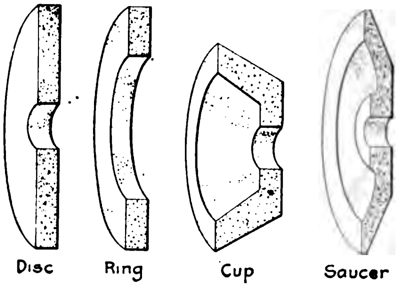


FIG. 260.—Shapes of wheels.

A comparison of the tables of wheel grades (Table 11) shows how necessary it is for the purchaser to designate the maker's name as well as the grade, size, shape, etc.

How Are Wheels Classified as to Their Shape?—Wheels are made in a large variety of shapes and sizes. They are differentiated in shop talk by their general shape as *disc wheel, ring wheel, cup wheel, "saucer"* or *"dish" wheel,* etc., Fig. 260. The particular shapes and sizes are, however, catalogued by their makers by numbers, often adding the name of the manufacturer of the machine in which they are to be used. The standard face shapes of the ring wheels or the disc wheels are denoted by capital letters (see Fig. 261).

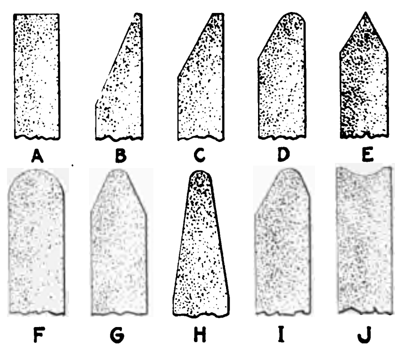


FIG. 261.—Wheel faces.

How Are Wheels Finished?—All wheels are finished after baking. The two sides are trued up parallel and brought to the required thickness of the wheel. The lead bushing is then poured into the rough hole. The wheel is next mounted on an arbor between bushings and the face trued to the desired shape.

How Are Wheels Tested?—Every wheel is tested before shipment, by being run on a testing machine at the rate of

about 9,000 surface feet per minute. This gives a strain of 250 pounds per square inch which is more than twice the stress of 6,000 feet per minute surface speed, which speed is recommended for actual practices.

250. Comparison of Grinding Wheels.

What are the advantages of the vitrified wheel?

1. It is very porous which makes it free cutting. The wheel does not quickly clog up with the particles of the metal being ground.

2. The bond itself is hard, and acts as an abrasive.

3. The process of manufacture makes for uniformity in the grade of the wheel. It does not contain "soft spots."

4. It is unaffected by water, acids, oils, heat or cold.

What are the disadvantages of the vitrified wheel?

1. The process of making is slow. Special orders cannot be quickly filled.

2. The larger wheels sometimes become cracked in the kiln, causing additional delay in filling orders.

3. It is impracticable to make wheels over 30 in. in diameter by this process.

4. The intense furnace heat slightly impairs the cutting quality of the abrasive.

What are the advantages of the silicate process?

1. Wheels can be made in a few days.

2. Large wheels are safe and dependable.

3. The heat required in baking does not impair the cutting quality of the abrasive.

4. By this process, wheels may be made on wire webbing or on iron backs which increase the safety.

What are the disadvantages of the silicate process?

1. The silicate wheel is not as free cutting as the vitrified wheel.

2. Hard and soft spots may occur, unless very skillfully tamped when molding.

What are the advantages of the elastic wheel?

1. The elastic wheels have great tensile strength and even when very thin, are safe and efficient.

2. Elastic wheels are smooth cutting, giving a beautiful finish, wet or dry.

3. Owing to their elasticity, deep side cuts may be taken.

4. Being a very compact wheel and elastic, they keep their shape well, even in the corner cuts, such as saw-gumming.

5. The elastic bond allows a wider latitude in the selection of the grain and grades.

6. Elastic wheels are especially efficient when grinding brass.

What are the disadvantages of elastic process?

1. Cost more than either vitrified or silicate wheels.

2. Not a porous, free-cutting wheel.

3. Will not stand much heat.

4. Not efficient except in sizes and shapes where the use of vitrified or silicate is impracticable.

251. Selection of Grinding Wheels.

When Are Soft Wheels Used?—The softer wheels are used on the hard materials. This is because the cutting edges even slightly dull do not do good work when grinding hard materials and hence should break away easily in order to bring new edges to the work. Certain alloy steels, hardened steel, and cast iron are hard materials and should be ground with soft wheels. Softer grades of wheels are used in proportion as the penetration (depth of cut) or the arc of contact is increased. For example, a softer grade wheel is used to grind a large diameter than is used to grind a small diameter, other things being equal, since the arc of contact is greater. For the same reason, surface grinding requires a softer wheel than cylindrical grinding on the same materials; and internal grinding, where the arc of contact is still greater, requires a still softer wheel. Further, the wider faced wheel in contact with the work should be softer than the narrow faced wheel.

When Are Harder Wheels Used?—The harder wheels are used on soft steel and annealed carbon steel, because the soft wheel wears away before the cutting edges become dull, and the wheel is therefore wasted. The mistake most often made in selecting grinding wheels is to get them too hard. It is a false notion of economy. Better have a wheel too soft than too hard.

A medium grade wheel should be used on brass and bronze, because a hard wheel is apt to fuse the chips, become clogged and glazed, and heat the work.

When Are Fine Grain Wheels Used?—Very fine grain wheels are seldom used, except in elastic wheels. The idea that a fine grain wheel is necessary to give a beautiful finish is wrong.

When Are Coarse Grain or Medium Grain Wheels Used?—A comparatively coarse grain (24 to 46) gives the best results for nearly all grinding operations, both for amount and accuracy of work, and also for finish. A coarse grain wheel will best serve to rough out the work, because the penetration can be deeper, and for the same reason it is the most efficient wheel for surface grinding. Wheels of medium grain (46 to 60) are used for grinding brass and copper.

What is a "Combination" Wheel and What Are Its Advantages?—The combination wheel is made up of abrasive grains of different sizes, for example one of the numbers, 24, 30, 36, with 60 or 80. The combination forms a very compact wheel that is very efficient for all around work. It will hold its shape longer and give a better finish than a coarse grain wheel and will cut faster than a wheel made entirely of the finer grain.

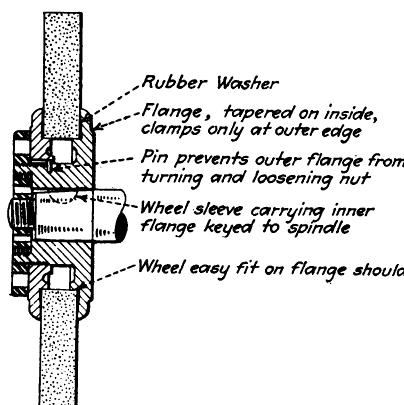


FIG. 262.—Mounting an abrasive wheel.

252. Caring for Grinding Wheels.

How Should a Grinding Wheel Be Mounted? (Fig. 262).—A wheel should fit easily upon the machine spindle (or wheel sleeve), yet not loosely, for if loose, it cannot be accurately centered, and is consequently out of balance. Paper should be wrapped around the spindle to make a wheel fit when the hole

is too large. On the other hand, a wheel that fits a trifle tight should never be forced on a spindle as this may cause it to crack.

If the hole is only a slight amount under size, it can be easily enlarged with an old file; or, if lead bushed, a jack knife can be used to cut out enough metal to make the wheel fit easily on the spindle.

The flanges between which the wheel is secured should be at least one-third of the diameter of the wheel; it is better to have them nearer one-half that diameter. They should be relieved on the inner side, so that they bear against the side of the wheel only at the outer edges. This serves to hold the wheel more securely with less pressure on the nut and with less likelihood of breaking the wheel. The inner flange should be keyed, or otherwise fastened securely to the wheel sleeve to prevent it from turning and loosening the clamping nut.

Washers of leather, blotting paper, or rubber should be placed between the bearing surfaces of the flanges and the wheel. Some makers attach a ring of heavy blotting paper to each side of their wheels for this purpose, but it is good plan to use a leather or rubber washer in addition.

Why Should a Grinding Wheel Be Balanced?—Any rapidly revolving element in a machine should be "balanced;" that is, no half of its weight about its axis should be heavier than the opposite half. Machine parts such as pulleys, flywheels, driving wheels, etc., must often be balanced even after turning, Balancing is accomplished by adding weight to the light side or taking weight from the heavy side.

A revolving part out of balance absorbs more power, causes greater wear in the bearings, sets up undue vibrations and, in the larger pieces especially, is more likely to break. It will be readily understood then how important it is that grinding wheels shall be in practically perfect balance.

Because of the fact that it is impossible to manufacture wheels of exactly even density in all portions they are balanced before they leave the factory. In the smaller sizes, say under 10 in. diameter 1 in. face, they require no further attention, but in the larger sizes, as the wheel wears, an out of balance

condition may develop that will defeat good work and may prove a positive danger. Therefore the larger wheels should be tested occasionally and if necessary corrected.

In grinding machines using large wheels provision is often made for balancing by having a suitable weight on one of the wheel flanges that may be shifted as desired. Also certain wheel makers provide a lead bushing a part of which may be removed to balance the wheel.

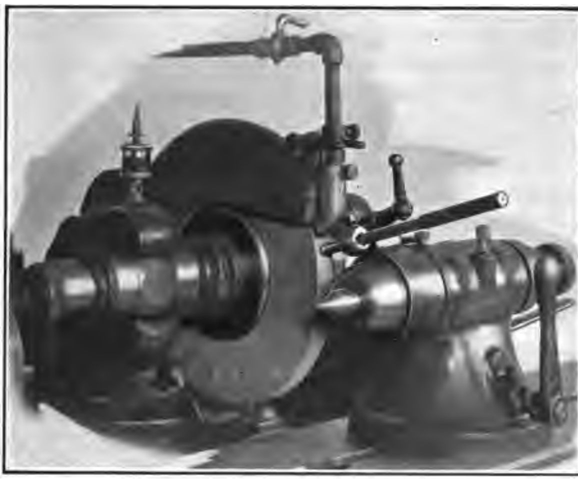


FIG. 263.—Truing the face of a grinding wheel.

How May a Wheel Be Sharpened and Trued to Shape? (Fig. 263).—It is of great importance that the wheel to be kept true and sharp. The best tool for this purpose is the diamond-tool, which is a small, black, rough diamond, held in the end of a suitable holder. Provision is usually made for holding the diamond-tool on the machine, or by means of an attachment, and except when unavoidable, the wheel should never be "trued by hand." Always make sure, *before using*, that the diamond is firmly held in the holder, and when set for truing, be sure the holder will not be ground away and the diamond lost. It is better to use a good flow of water if possible, when truing a wheel: the particles of abrasive do not

scatter and the life of the diamond is lengthened. Move the diamond across the face of the wheel slowly. Do not take too much at one cut because this tends to unduly break up the face of the wheel, and do not waste the wheel by truing off more than is necessary.

Questions on Grinding Wheels

1. Examine an abrasive wheel. What shape is it? What diameter is it? How wide is the face? What size hole has it?

2. Is the wheel you are examining hard, medium or soft? Is it coarse or fine? Is it sharp? Is it glazed?

3. Emery cloth, sand paper, oil-stones and grinding wheels are made of abrasives. What is an abrasive?

4. Why does an abrasive *cut?*

5. A piece of steel may be hardened and "tempered." A commercial abrasive has a wonderful temper. What do you understand by the term "temper?"

6. What is the difference between emery and corundum?

7. What is the difference between corundum and carborundum?

8. State two reasons for the use of artificial abrasives.

9. Some grinding wheels may be easily scratched with a knife or a file, others with difficulty. How do you explain this?

10. What is the definition of the word "vitrify?"

11. What is a vitrified grinding wheel?

12. Name three "bonds" used in making grinding wheels.

13. What do you understand by the term "elastic" as applied to grinding wheels? Is the term suitable? Give reason.

14. Elastic wheels are nearly always used in bench lathe external grinding attachments. Why?

15. How are wheels classified as to *grain?*

16. Is this classification fairly uniform among the various manufacturers? Give reason.

17. How are wheels classified as to *grade?* Is this classification standardized?

18. If you were ever required to write an order for grinding wheels, what information as to sizes, etc., would you furnish the dealer?

19. Are you able to find in any catalogue the wheel makers' suggestions as to the proper way of arranging this information?

20. What is the purpose of the soft washers used in mounting a grinding wheel?

21. State three facts concerning the flanges between which the wheel is mounted.

22. What are some of the reasons for balancing a wheel?

23. Give four suggestions concerning the use of the diamond.

CHAPTER XVI

GRINDING PRINCIPLES AND PRACTICE

253. Introduction.—Grinding is the process of removing metal by means of an abrasive wheel. The results which may easily be obtained, with the proper wheel in a well-made machine intelligently operated, are extreme accuracy, a fine finish and rapid production. The work may be of any size or shape within the capacity of the machine and of practically any of the materials, hard or soft, used in machine construction. The grinding machine is the only standard machine tool for the accurate sizing of hardened pieces.

The grinding machine is primarily for finishing surfaces that have previously been roughed out in another machine, hence its value lies not in the amount of metal removed in a given time but in the accuracy of its product and in the ease by which this accuracy may be obtained. That is, cylindrical or tapered pieces may often be finished in a grinding machine quicker, better, and cheaper than they could be turned to exact size; holes in many of the parts made of the tough alloy steels or even of cast iron may be ground easier and quicker than they can be bored to size or reamed; and many flat surfaces may be finished and accurately sized in the surface grinding machine, especially with the use of the magnetic vise, more efficiently than in any other machine.

The grinding machine is not a polishing machine. The surface properly ground is beautifully smooth and free from feed marks, scratches, or chatter marks. Such a surface is just as accurate for commercial purposes as a highly polished "looking glass" or "nickel plated" finish. Don't waste time taking half a dozen finishing cuts when grinding, any more than you would take half a dozen finishing cuts when turning.

254. Kinds of Grinding.—By *cylindrical grinding* is meant the grinding of outside cylindrical surfaces; most grinding is cylindrical. External tapers and angles may be ground and the same principles of wheel action, work speeds, wheel speeds, etc., apply as in cylindrical grinding. By *internal grinding* is meant the grinding of holes either straight or taper. By *surface grinding* is meant the grinding of horizontal flat surfaces. When the flat surface being ground is vertical, the operation is called *face grinding*. In face grinding the face (periphery) of the wheel may be used as when grinding the side of a revolving disk (see Fig. 272) or the side of the wheel may be used if it is under cut a trifle (see Figs. 271 and 278).

When grinding cylindrical, taper, or angular pieces, whether external or internal, several chips are usually taken by the *traverse method* of grinding. That is, the automatic cross feed for the wheel is set to operate a definite amount for the depth of cut, then the revolving work is fed longitudinally by the table traverse.

Frequently when grinding comparatively short work with not over .010 or .012 in. to be removed from the diameter, it is advisable to set the wheel to grind the correct diameter and then grind the succeeding pieces without changing the cross setting of the wheel, except occasionally to compensate for the wear of the wheel. This is spoken of as *"set wheel" grinding*.

In recent years plain grinding machines have been designed to permit of using wide faced wheels and in manufacturing operations it is not uncommon to find wheels up to 6″ face. When the work is shorter than the width of the wheel face, it does not have to be traversed, it is only necessary to feed the wheel in as the work revolves. This is called *"straight in" grinding*.

With the wide faced wheel and a suitable fixture for dressing the wheel to a given outline it is possible to grind a more or less irregular surface, for example when crowning pulleys, finishing handles, etc. This is termed *form grinding*. Form grinding is not recommended for work having sharp corners to finish

or where the difference between the largest and smallest diameters of the work is over ½ in.

255. Factors in Successful Grinding.—Assuming that the operator is "on his job" or at least under intelligent supervision, economical production in grinding depends on (1) the machine, which must be of ample size and power, rigid in construction, carefully cleaned, oiled and adjusted; (2) the grinding wheel, especially the grade and grain; (3) the wheel speed; (4) the work speed; (5) the table feed; and (6) the amount of cross feed (wheel penetration or chip or depth of cut) for each table traverse.

All of these factors depend more or less upon each other. For example, if a wheel soft enough is not available, the harder wheel may be used, but the work speed should be *increased* or the wheel speed *decreased* as compared to the speed that would be correct for the softer wheel. That is, increasing the work speed or decreasing the wheel speed wears the wheel faster, in other words, the wheel does not glaze so quickly; it *acts* as a softer wheel. However, the depth of cut cannot be as great and production is therefore lessened. To understand and use the best possible or best available combination of factors is the art of grinding.

No set of rules can be given for the correct work speed, amount of feeds, etc., for the grinding machine. So many variables enter into the consideration of these things and the factors dovetail into each other in so many respects, one depending upon the other, that decision must rest upon the judgment of the operator or the foreman. *Judgment* is the sum of knowledge of principles plus experience. Fortunately certain of the fundamental principles concerning the factors of grinding may be set down. Developing ideas by the practical application of principles is experience.

PRINCIPLES OF GRINDING

256. Care of Machine.—Nobody can hope to progress very far in the operation of a machine if he is ignorant of

the features of its construction. Study these features and learn to manipulate the machine expertly. The machine should be *clean* and carefully adjusted and oiled. The belts should be fairly tight, in good condition, and free from lacings, etc., that will tend to set up vibration as they go over the pulleys.

257. Setting-up the Work.—Have the centers and center holes in first-class condition and *clean*. If the work is to be chucked or held in a vise or clamped otherwise, have the holding device and the work clean, and be extremely careful in clamping. Remember that a very little dirt or a slight strain that will twist or buckle or bend the work will defeat good grinding.

258. Grade of Wheel.—To produce a suitable finish on hard materials, a sharper cutting edge is required than is necessary for softer materials, therefore a softer wheel, in which the slightly dull particles of abrasive will more easily break away under the cutting pressure, is used in grinding the harder materials such as hardened steel and cast iron.

Unhardened carbon steel and untreated machine steel and alloy steel may be economically ground to an excellent finish with cutting points that are worn somewhat duller than would produce an acceptable finish on the harder materials, therefore a wheel somewhat harder, that will retain its cutting particles longer, may be used on soft steel.

In grinding the still softer materials such as brass, bronze, copper, hard rubber, etc., the pressure of the work against the wheel is not so great as in grinding soft steel therefore a soft wheel must be used or the cutting particles will be retained too long.

As a matter of fact, soft or medium soft wheels are more economical than hard wheels for practically any grinding operation. Do not select wheels harder than grade T (Norton grade) for any material and rarely harder than grade M. (See page 410.)

259. Grain of Wheel.—A coarser grain wheel penetrates easier and cuts more freely than a fine grain wheel. A suitable

commercial finish can be obtained with a wheel as coarse as 24 if carefully trued with a blunt diamond. The tendency is to get away from the finer wheels as it is also to get away from the harder wheels. If, however, an exceptionally fine finish is desired, it may be advisable to rough grind with a coarse wheel and finish with one of finer grain.

For a variety of work in run of shop jobs the combination wheel (see paragraph 251) is recommended.

260. Speed of Wheel.—The surface speed of an abrasive wheel should be from 5,500 to 6,000 feet per minute. This is safe and nothing is gained by running it faster. It may be advisable to run it slower to have it act softer but it is unwise and it may be dangerous to run it faster than 6,000 feet per minute. Do not get revolutions per minute confused with surface speed. As the size of the wheel decreases noticeably the revolutions per minute may properly be increased. Remember always that when a wheel of larger diameter is substituted for a smaller wheel, the speed of the spindle should be *decreased.*

RULE I.—To obtain surface speed, diameter of wheel and revolutions per minute given, multiply revolutions per minute by one-fourth the diameter of the wheel

or $$\text{surface speed} = \text{r.p.m.} \times \tfrac{1}{4} \text{ dia.}$$

RULE II.—To obtain the necessary number of revolutions per minute to give the desired cutting speed, having given the diameter of the wheel, divide the surface speed required by one-fourth the diameter of the wheel

or $$\text{r.p.m.} = \frac{\text{surface speed}}{\tfrac{1}{4} \text{ dia.}}$$

For derivation of formulas see paragraph 170, page 217.

261. Speed of Work.—The grinding wheel can do only so much cutting. Bearing a tool too hard on the wet grinder does not sharpen it any faster but does result in wearing the wheel and possibly in overheating the tool. By the same principle, revolving the work too fast in the grinding machine

does not produce more work but does result in wearing the wheel and possibly in injury to the machine.

As a help to the beginner the following table of (average) work speeds is given:

SURFACE SPEED OF WORK IN FEET PER MINUTE

Operation	Soft steel	Hardened steel	Cast iron	Bronze
Roughing..........	50	25	40	60
Finishing..........	75	40	60	75

Be sure the wheel speed is right, then if the wheel wears rapidly decrease the work speed. If the wheel glazes or loads with the material being ground, either use a softer wheel or dress the glazed wheel with the diamond and increase the work speed.

For finishing, the cut is lighter and the work speed may be increased as noted in the table.

262. Arc of Contact.—The distance the cutting edge moves through the metal while peeling off its chip is the arc of contact of the wheel and work. As the diameter of the work increases the given wheel has a longer arc of contact, cuts a longer chip. Removing the same amount of metal in a given time taking *longer* chips means taking *thinner* chips. Taking a long thin chip requires less cutting pressure than removing the same amount of metal by a shorter thicker chip. Hence, the given wheel will wear longer, that is it will appear to be harder, when grinding the larger diameters. For instance, a wheel that is right for tool steel 1 in. diameter at 25 feet per minute will appear too hard when grinding tool steel 3 in. diameter at 25 feet per minute. This is why it is advisable to use softer wheels for larger diameters, still softer for surface grinding and softer yet for internal grinding. Increasing the work speed will have relatively the same effect.

263. The Table Feed.—The more cutting edges of a suitable wheel that come in contact with the work in a given time the greater the production. Consequently, in traverse

grinding, if the nature of the work will permit and maximum production is expected, the table feed for roughing should be arranged to move the work an amount substantially equal to the width of wheel face each revolution of the work. When finishing, the work speed is increased and the table traverse is usually unchanged which results in a feed somewhat less than the full width of wheel face.

Where possible, it is a good plan to set the reverse dogs to allow a portion of the wheel face to extend beyond the end of the surface being ground.

In universal grinding machines the width of wheel used is not usually over 1 in. but plain grinding machines are built which take a wheel with 10 in. face. When the length of the surface being ground is less than the face of the wheel it is unnecessary to traverse the work. The straight-in method of grinding is used (see paragraph 254).

264. Depth of Cut.—Given a wheel of proper grain and grade, the right wheel speed and work speed, then the depth of cut is limited only by the nature of the work and the power of the machine. The idea that, in grinding, a series of infinitesimal cuts should be taken is wrong. It is safe to say 1,000 cuts are taken that are too light to one that is too heavy. The usual faults in cross feeding are (1) irregular hand feed and (2) too light a feed. It is practically impossible to feed by hand without sometimes feeding too much and at other times too little; *use the automatic feed.* Do not take one tooth feed for roughing, take eight or ten teeth and very likely the job will stand twice that or even more.

265. Amount of Stock to be Left for Grinding.—The amount of stock to be left for the grinding operation depends largely on the character of the work, whether the piece is long or short, stocky or slim, what the material is, if it is to be hardened what the facilities are for straightening, and the nature of the turning whether it is fairly smooth or not. It might be good practice to leave only .005 in. on one piece while on another piece it would be economical to leave 1/32 in. for grinding. This is a matter of judgment and requires experi-

ence. Manufacturers usually supply limit gages[1] to the lathe hands who rough turn the work.

266. Roughing and Finishing Cuts.—In the modern grinding machine the work speed, cross feed, and table feed are independent of each other. That is, any desired table feed, coarse or fine, may be used on work of any diameter, the work of course revolving at the proper speed for that particular job. The cross feed may be set for any desired amount. Consequently the combination of work speed, table feed and cross feed may be used that in roughing will serve to most quickly remove the metal, and in finishing will give the kind of surface desired.

It will of course depend upon the size of the work, the number of pieces, the degree of accuracy required, etc., whether it will be better to rough and finish in one setting, or to rough all the pieces before finishing any. In either case it will be advisable to take two or more light cuts when finishing. It will be advisable also to decrease the table feed to two-thirds or three-quarters of the roughing feed, or to increase the work speed a relative amount which will give the same result.

267. Causes of Inaccurate Work and Imperfect Appearance. Time may be wasted and poor work result by the use of a wheel so soft that it will not hold its shape the whole length of cut. This is especially true in surface grinding. Most of the spoiling of ground work is, however, caused by the heating and consequent springing of the work, due to a hard wheel, a dull wheel or a loaded wheel. Chatter and waviness in the work may be caused by the wheel spindle being loose in its bearings, the wheel out of balance, or the wheel being clogged with chips, but the most frequent cause is the wheel getting out of shape, either out of round or the face not parallel to the cut. *Keep the wheel clean and true and sharp.*

[1] *Limit Gage.*—A double gage having one dimension larger and the other smaller than the nominal size. With narrow limits these gages are valuable for testing the finished product. They are also much used in lathe work (rough turning) with wider limits over and under the nominal turning dimension.

268. Causes of Wheel Wearing Too Rapidly:

1. Wheel too soft.
2. Face of wheel too narrow.
3. Speed of wheel too slow.
4. Speed of work too fast.
5. Crowding the wheel.
6. Holes or grooves in the work.

269. Causes of Wheel "Glazing."

1. Wheel too hard.
2. Grain too fine.
3. Wheel speed too fast.
4. Work speed too slow.
5. Wheel loaded with chips.

270. Causes of Wheel Getting Loaded.—When grinding soft materials such as brass, bronze, aluminum or even soft steel, there is a tendency for the chips to wedge in between the cutting points of the wheel in the same way that a file is loaded. This is especially true when it is attempted to remove too much material in a given time with a wheel that is too hard or when the work is running too slow. The remedy is to do one or more of the following: Select a softer wheel; increase the work speed; decrease the amount of chip, and perhaps the amount of table feed if the width of the cut seems to cause the work driving belt to slip.

271. The Use of Cutting Lubricant in Grinding.—Provision is made in most grinding machines for keeping a steady flow of cutting lubricant directed on the part of the work where the wheel touches.

In the smaller types of grinding machines, cutter grinders and tool-makers' surface grinders, etc., this feature is not provided, but in the external and internal cylindrical grinding machines and larger surface grinding machines, it is an absolute necessity. An uneven temperature of the work will cause distortion and a consequent inaccuracy. The flow of compound serves to prevent this, and serves also to keep the wheel clean and free cutting which makes for greater production.

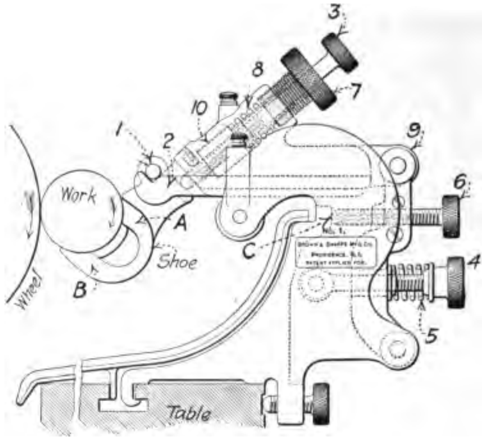


FIG. 264.—Brown & Sharpe universal back rest or steady rest.

To adjust the universal back rest proceed as follows:

First.—Select shoes the size of the finished work and hook the trunnions 1 into the Vs 2.

Second.—Turn screw 3 back far enough to allow the shoe to clear the work and loosen nut 4 to entirely relieve the pressure on spring 5. Turn back screw 6.

Third.—Turn forward the screw 7 until a light pressure is given to the spring 8. Turn forward the screw 3 and, if the spring 5 is wholly relieved and the screw 7 is far enough back, the shoe will come in contact with the work at both points *A* and *B*.

Fourth.—Press lightly with the thumb on 9 holding the shoe in gentle contact with the work, and turn the screw 6 carefully, noting the slightest touch of the end against the stop *C* in order that none of the parts be moved. With this screw in contact with the stop, the shoe should bear alike at both points *A* and *B*. Turn nut 4 to give some pressure to the spring 5. The combined pressure of the springs 5 and 8 should be only sufficient to resist the pressure of the wheel when taking the last cut and to prevent vibration of the work under any cut that it may be desirable to take. Tighten the clamping screw to hold screw 3.

Fifth.—Grind the trial piece of work, moving the screw 3 to maintain the contact of the shoe with the work and the screw 6 to preserve the relative diameters at the various points. As the work approaches the finished size, measure at the different rests, after each cut.

After the first piece is finished with the diameters alike at all points, the shoe should bear alike at *A* and *B* and the sliding nut 10 should rest against the shoulder.

Leave the parts in this relation and grind the other pieces of work, adjusting screw 3 only as the shoe wears and screw 6 for the delicate adjustment for diameter. Note the effect of the adjustment upon the sparks to determine the approximate position.

When work is to size, the nut 10 and the screw 6 are intended to rest against the shoulder and stop, to prevent further pressure of the shoe upon the work The shoe and wheel will be left in the proper position for sizing duplicate pieces.

When unground work is placed on the centers and in the shoe bearings, the nut 10 and screw 6 will be forced away from the shoulder and stop, thus compressing the springs 5 and 8.

Should the shoe bear unequally on *A* and *B*, tighten screw 4 to increase pressure at *A* and screw 7 to increase pressure at *B*. Do not make the combined pressure of these springs greater than necessary, as long and slender work, although of uniform diameter, may not be straight when released from the shoe unless some allowance is made for elasticity.

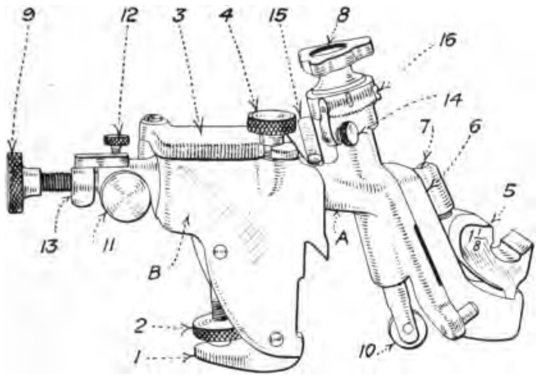


FIG. 265.—Norton steady rest. This illustrates the design of steady rest as used on the 6 in. and 10 in. machines. (*Norton Grinding Co.*)

The adjustable support "A" can be raised, lowered, or moved horizontally. The body "B" is clamped on the machine with the clamp (1) and thumb nut (2). The cover (3) is held in place by the thumb screw (4) and when the screw (4) is released, can be swung on the pivot to permit the removal of the adjustable support "A."

The work-shoe, or bearing (5) is hardened and ground to size. This shoe is placed in the holder (6) and clamped in place by the screw (7). This shoe has a bearing in the holder on three points, thus insuring rigidity. The holder (6) can be removed from the support "A" by simply lifting it off.

The vertical adjustment is made with the knob (8) and horizontal adjustment with the screw (9). The wheel (10) rolls freely on the resting surface of the work table and allows free horizontal motion of work that is not true and straight before grinding. The knob (11) is used to clamp the screw (9) when necessary. The adjustable stop (13) is threaded on the screw (9) and allows free motion until the correct size is obtained on the first of a number of duplicate pieces of work. Then it is made fast to the screw (9) by the clamping screw at (13). The screw (9) can then be turned back to allow an unground piece of work to be placed on centers and ground, the screw (9) being moved from time to time as grinding proceeds, until the stop screw (12) shall limit the motion and give accurate duplication of work. The stop screw (12) allows delicate adjustments for exact size of work. The stop screw (14) serves the same purpose for the vertical adjustment of the rest, coming in contact with the stop piece (15). The clamp screw (16) holds the stop firmly in contact with the knob (8). Wood work-shoes can be used in place of the holder and hardened shoe, here shown; the wood shoe and holder being in one piece.

There are several specially prepared compounds in the market which, when mixed with water, are very satisfactory, and the grinding machine or abrasive wheel manufacturers are glad to recommend certain brands.

If clear water is used, it will rust the machine and the work, and to prevent this just enough sal-soda is added to show a slight deposit on the finished work when dry. Many machinists add a small quantity of oil which serves to give a better finish on the work.

272. The Advantage of Using Dead Centers in Grinding.— The work, revolving with the headstock spindle, may be

FIG. 266.—Shows back rests in use.

held on centers, in a chuck, on a face plate, or directly in the taper hole of the spindle. In addition, the grinding machine is provided with means of driving the work on dead centers.

The work itself having good clean centers and ground *on dead centers* in the machine must come true and absolutely concentric. If, however, the live center revolves with the work any fault in the spindle bearings will affect the accuracy of the work. Moreover, if the live center runs out ever so little, the work in being ground will be that much out of center or eccentric. The grinding machine is essentially an accurate finishing machine, and the work it has to do is not proportionately as heavy as that which a lathe is required to do.

Therefore, a large proportion of the cylindrical work may be ground on dead centers.

273. The Use of Back Rests or Steady Rests.—The back rest, or "steady rest" is necessary when grinding slender work, and grinding machine manufacturers have developed back rests with considerable flexibility when the work is in the rough, but which are provided with positive stops which insure the accuracy of the finished piece (see Figs. 264 and 265). That is, they may be adjusted to compensate for work which is considerably oversize, out of round, or slightly bent. When, however, a plain rest is used (and often with a compensating back rest) it is advisable to "spot" the work for the rest by feeding the wheel in by hand until the diameter is .002 or .003 in. oversize (see *A*, Fig. 267). This operation takes only a short time, eliminates much of the tendency otherwise for the work to "chatter" and makes for longer life of the shoe.

Questions on Grinding 1

1. What do you understand by the terms "grinding" and "polishing?"

2. What do you understand by "commercial grinding?"

3. What do you understand by "efficient grinding?"

4. State at least five things necessary to accomplish a real job in grinding.

5. What is meant by traverse grinding? Set-wheel grinding? Straight-in grinding?

6. Is form grinding straight-in grinding? Explain.

7. Can you explain why understanding the construction of the machine will increase your production? Can you give an example?

8. Can you state why habits of reasonable care will increase production?

9. What does increased production mean to you personally?

10. Should the surface speed of a grinding wheel be more or less than a mile a minute? About how much? What do you understand by a "safe" speed?

11. How many revolutions per minute will be a safe speed for a 10 in. wheel?

12. How do the work speeds for roughing and finishing soft steel, cast iron and bronze in a grinding machine compare with speeds for turning these materials in a lathe?

13. Why is it that a soft wheel is used for grinding hardened steel and also for the soft materials such as bronze and copper, while a harder wheel is used on machine steel, a material of medium hardness?

14. A wheel may act harder or softer according to the work speed. How do you account for this?

15. Why are softer wheels used for larger diameters than for smaller diameters of the same material?

16. Does the same principle (as in Question 15) apply in surface grinding and internal grinding? Explain.

17. What effect in grinding has the *grain* of the wheel?

18. A few years ago the machinist set the table traverse to feed anywhere from a thousandth to a sixty-fourth of an inch per revolution of the work. What is the modern practice? Have you tried it?

19. Also it was the practice to take about half a thousandth chip. What is the modern practice in efficient grinding?

20. Occasionally it is advisable to feed the wheel in by hand but usually it is best to use the automatic cross feed. Explain.

21. Why is a coarse wheel used in roughing? Why is a coarse wheel satisfactory for many finishing operations?

22. What is the advantage of the combination wheel?

23. What is meant by penetration?

24. On one job it may be advisable to leave $\frac{1}{32}$ in. for grinding, on another job only about .005 in. How do you explain this?

25. What is the advantage of having work speed and table traverse independent of each other.

26. If you had, say, 100 pieces, easy to handle, how would you proceed to rough and finish grind them? Why?

27. Might it be advisable to rough and finish larger, heavier pieces in a different way? Explain.

28. If production is not up to standard quantity and quality, what would you suggest as possible causes?

29. What do you mean by a wheel being loaded? What does it indicate?

30. How do you account for a wheel becoming glazed?

31. How are wheels wasted?

32. What is the primary reason for using cutting lubricant? State two other reasons.

33. Explain the advantage of grinding work on dead centers.

34. Do you understand the value of back rests? Do you understand the construction and adjustments of the back rests on the machine you are using?

35. Having studied this subject thus far, just what are your ideas concerning a superior grinding machine? The best wheel to use? An intelligent operator?

GRINDING OPERATIONS

274. A Few Suggestions.

1. Be sure the wheel is guarded.

2. Do not use a wheel that is not sound. Tap it lightly with a hammer and listen for a clear ring.

3. Remember to change the revolutions per minute of the wheel spindle if a larger or smaller wheel is substituted.

4. Always dress a wheel after substituting it for another; running out ever so little will defeat efficient production.

5. If the wheel does not go on the spindle easily, scrape the lead bushing a little, perhaps with a pocket knife.

6. Never take a diamond tool away from the tool-room without first making sure the diamond is firmly held in the holder. You may get charged for a diamond you did not lose or you may lose a diamond someone else has loosened.

7. An abrasive wheel, like any other cutting tool, gets out of shape and dull, dress (sharpen) it occasionally.

8. See that the grinding machine centers are smooth and clean and that the work centers are of good shape, cleaned from dirt and well-oiled.

9. Be careful to *know* that the feed reverse dogs are correctly adjusted.

10. When setting up, cleaning or oiling, it may be necessary to move the table by hand. Move the wheel out of the way first.

11. Don't forget that moving the table lengthwise is likely to stretch the belt from the overhead pulley drum to the headstock unless the belt is running. Pull the belt by hand if necessary.

12. Clean the swivel table thoroughly before moving the tailstock or headstock.

13. Don't attempt to grind when the belts slip; pay especial attention to the wheel driving belt.

14. Always keep measuring tools and gages covered when not in use.

15. When finish grinding if it is necessary to stop the

machine for a considerable time as for lunch or overnight, do not start to grind as soon as the machine is started. Many pieces have been spoiled in this way. Let the machine run for 5 minutes and warm up.

275. Operations in Grinding a Cylinder.

1. Be sure the wheel is true and sharp. If in doubt use the diamond.
2. Fasten the suitable driver on end of work.
3. Clean and oil both centers of work.
4. Bring tailstock to position (so that tail center has proper tension against work.)
5. Adjust the right reversing dog so that a portion of the face of the wheel runs over the end of the work, and the left reversing dog so that the side of wheel will approach nearly to work driver.
6. Note the wheel speed.
7. Set the work speed.
8. Set the table feed.
9. Set the automatic cross feed.
10. Spot for the back rests if necessary.
11. Adjust the back rests.
12. Rough grind to within .003 in. to .005 in. oversize.
13. Set the cross feed automatic stop (first piece only).
14. After pieces are rough ground as above, change position of left reversing dog as desired, reverse the work on centers and rough grind other end of each piece.
15. When all pieces are rough ground, change the table feed, the cross feed (and possibly the wheel), true the wheel and proceed to finish practically as for roughing.

276. Grinding a Shouldered Piece.—(CAUTION. Owing to the probability that the center holes are not exactly the same depth in a number of shouldered pieces to be ground, or that, as in the case of a shouldered bushing, the pieces do not locate in the same position on the mandrel, great care must be taken not to allow the wheel to run into the shoulder.)

Where the width to be ground is less than the width of the wheel, it is most economical to feed the wheel in laterally by

hand until the work is down to size and then slowly run the work off the wheel (table traverse) to remove any lines caused by the wheel surface.

When grinding any considerable length of work to a shoulder the portion next to the shoulder should be finished to size by feeding the wheel in laterally by hand (see *B*, Fig. 267) and then, drawing back the wheel, finish the remaining portion in the usual manner of table traverse and automatic feed.

The table traverse reverse dog should be set to operate about 1/16 in. or more from the shoulder. While the table reversing dogs operate to reverse the table motion within a few

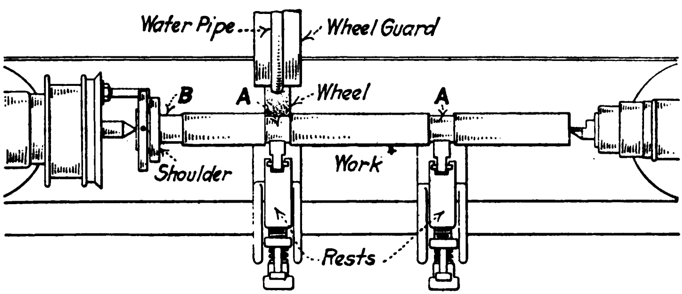


FIG. 267.

thousandths they do not form a positive stop, and by means of the traverse hand wheel the table may be easily moved 1/16 in. or more beyond the regular travel, which fact makes possible the cut close to the shoulder as above explained without moving the dog.

It will be more economical if shouldered pieces that are to be ground on the smaller diameter are previously turned (necked) to size or slightly smaller for a distance, depending on the diameter, of 1/8 in. or more from the shoulder.

Cutting with the corner of the wheel tends to round that corner, "dragging" the other corner tends to keep it sharp. In other words, if the work is fed against the wheel in one direction only, the edge of the wheel feeding against the chip will become slightly rounded, while the other edge will stay

square. Therefore, when a particularly sharp corner is required between the shoulder and the smaller diameter, and no previously turned neck is provided, it is usually best to do all or most of the cutting while feeding away from the corner. It is usually advisable to feed the shorter pieces by hand.

277. Grinding a Taper.—Tapers up to 2 in. per foot may be ground by setting the swivel table the desired amount as shown in Fig. 268. Remember the graduations are for convenience and do not depend absolutely upon them; *fit the*

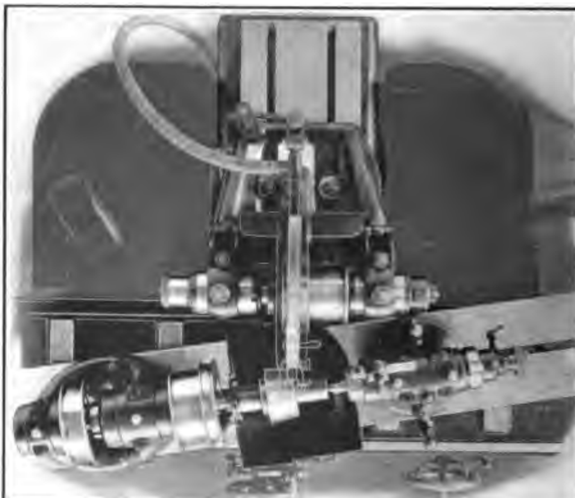


FIG. 268.—Grinding a taper.

taper to a gage. If difficulty is experienced in getting the swivel table adjusted exactly and the first piece is ground nearly to size, do not take a chance on spoiling this piece but put in another (unground) piece and try and get the exact fit while it is still somewhat oversize. The first piece can be finished without worry of spoiling after the table is set.

When grinding several tapers, shanks of end mills for example, unless the center holes are all of the same size there will be a variation of the size of the taper if the wheel is fed in a

like distance for each piece. Grind the pieces with the larger centers (headstock end) first and thus avoid danger or grinding any piece too small. The Norton Company make a "Taper Locating Attachment" which is very useful when a number of tapers are to be ground. This consists of an adjustable headstock center and a hinged gage. The piece is located in correct position by the gage, and the center adjusts itself (spring tension). The center is then clamped in position.

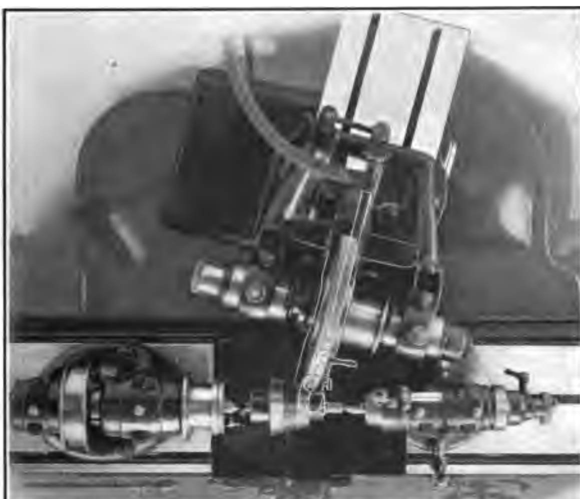


FIG. 269.—Grinding an angle. For a diagram of the set-up see Fig. 257.

278. Grinding an Angle.—In machine shop work a piece is called a *taper* when it becomes uniformly smaller toward one end by an amount not over 8° or 10° included angle (about 2 in. taper per foot), when it becomes uniformly smaller in greater degree it is called an *angle*.

To grind angles (work held on centers, Fig. 269), swivel the wheel stand slide bed to the required angle, then set the wheel stand at right angles to the movement of the slide so that the face of the wheel is parallel to the surface to be ground. Operating the cross feed will cause the wheel to feed in a

direction at an angle to the axis of the work, according to the setting of the wheel stand bed. To take a deeper cut, the *table* is moved a trifle by gently tapping the table traverse hand wheel. A set-up for grinding an angle is illustrated in Fig. 269 also in the line cut, Fig. 257.

A center may be quickly and accurately ground by swiveling the headstock as shown in Fig. 270 and driving by the live spindle driving pulley. In a similar manner a piece held in

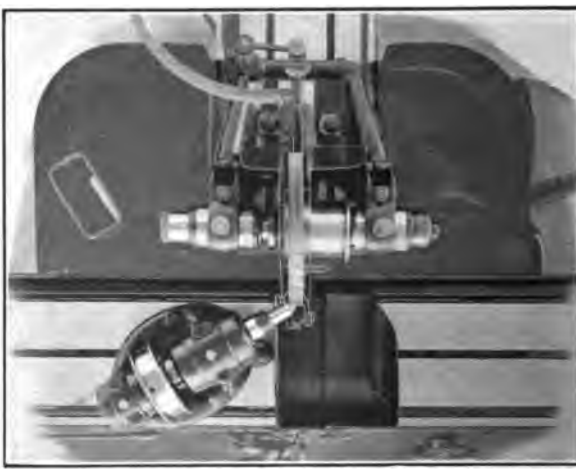


FIG. 270.—Grinding a center.

the chuck mounted on the headstock spindle may be ground at an angle.

279. Face Grinding (Figs. 271 and 272).—The figures show two methods of face grinding. In Fig. 271 the side of the wheel is undercut a trifle, the swivel table is carefully set straight and the wheel head slide bed must be at right angles.

Figure 272 shows a method of grinding work flat or if desired a trifle thinner toward the center, as for example a metal slitting saw. The work may be mounted on the face chuck and centrally located and securely held by means of an

expansion bushing and draw-in bolt (Fig. 273). If more convenient it may be held in a chuck. These accessories are usually furnished with the machine. If there is enough work of this character to warrant the cost of a magnetic chuck, no doubt such a chuck is most efficient. An ample flow of compound is necessary in face grinding if the work is thin, to keep it from warping.

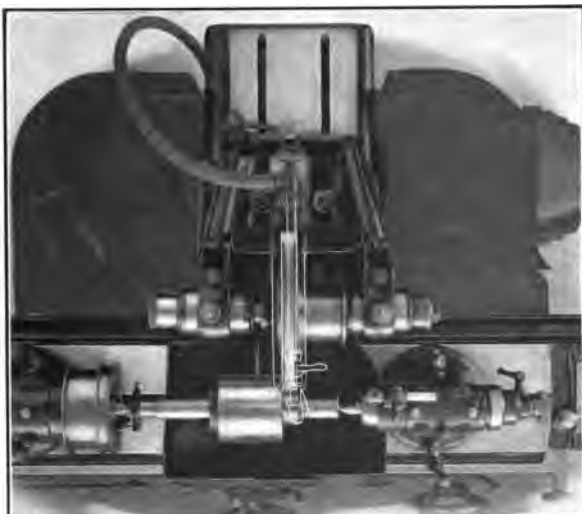


FIG. 271.—Shows a method of squaring the ends of bushings. The wheel should be very soft and relieved on the side, leaving a narrow cutting edge. If the axis of the arbor and the axis of the wheel spindle are exactly parallel the surface will be perfectly flat and at right angles with the axis. A convex or concave surface can be obtained by varying the relation of the axes. A wheel similarly turned away on the sides is shown in Fig. 278. A diamond tool is used to turn the face or sides of an abrasive wheel.

280. Internal Grinding Fixture.—If the number of holes to be finished in a manufacturing department will warrant the outlay, it is of course economy to have an internal grinding machine (Fig. 245) of the kind and size desired. For the average general machine shop and tool-room work, however, the internal grinding fixture with which all universal grinding machines are equipped and which may be quickly set up, will

be found very satisfactory for either straight or taper holes. Figure 274 illustrates this attachment.

FIG. 272.—Face grinding using face chuck shown in section in Fig. 273.

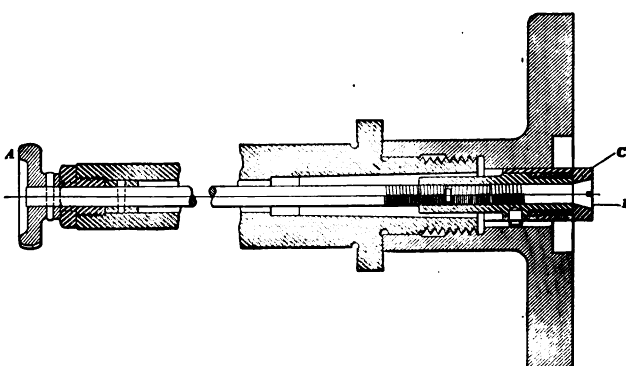


FIG. 273.—Section through headstock spindle (B. & S.), showing mechanism which operates face chuck. This chuck holds such work as thin cutters, saws, washers, etc. by means of an expansion bushing *C* which is expanded by the screw *B* and drawn tightly against the face plate by turning the knob *A*. Different sizes of bushings may be quickly substituted.

281. Internal Grinding.—Clamp the work carefully in order not to spring it in the slightest degree. As in cylindri-

cal grinding have the work revolve against the wheel, that is in an opposite direction to that of the grinding wheel. The

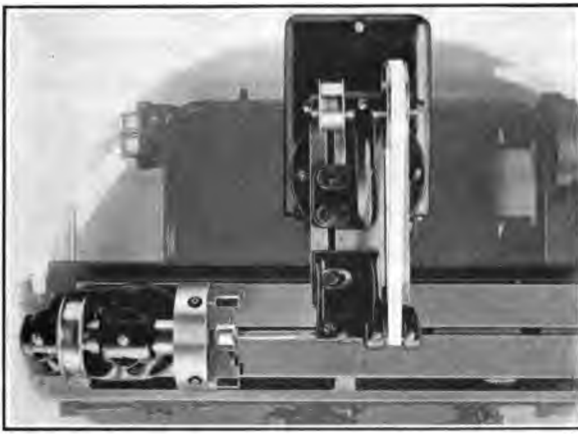


FIG. 274.—Internal grinding attachment in use in No. 1 universal grinding machine (B. & S.). The wheel stand is removed, the wheel stand platen is reversed (swivelled 180°) and the counter shaft bracket and grinding fixture bolted to the platen as shown. The countershaft and fixture spindle are connected by a small open belt and the belt from the overhead works to the countershaft is crossed to give the correct direction of rotation for the grinding wheel.

spindle of the internal grinding fixture runs from 10,000 to 16,000 r.p.m. (depending upon the size and kind) but even this speed will not give the proper surface speed to a small grinding wheel. For this reason, and for the further reason that so large a portion of the periphery of the wheel is in contact with the work, the work must revolve somewhat faster than for outside grinding and the wheel should be free cutting, that is, fairly coarse and very soft grade.

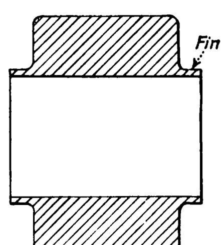


FIG. 275.

Generally speaking, the amount of metal left for internal grinding should be considerably less than for external grinding because inside grinding, especially in small holes, is much slower than outside

grinding. If an extremely accurate straight hole is required, as for example in a ring gage, it is better to leave a fin at either end as shown in Fig. 275. The fin is afterward removed and this will remove the slight "bell-mouth" that occurs at each end of the hole.

282. Grinding Taper Holes.—Taper holes are ground in exactly the same way as straight holes, except that the swivel table is adjusted to give the required taper. If a steeper taper than may be obtained by swivelling the table is required, the headstock may be swivelled.

SURFACE GRINDING

283. Surface grinding is accomplished by fastening the work to the table of the machine and causing it to feed under

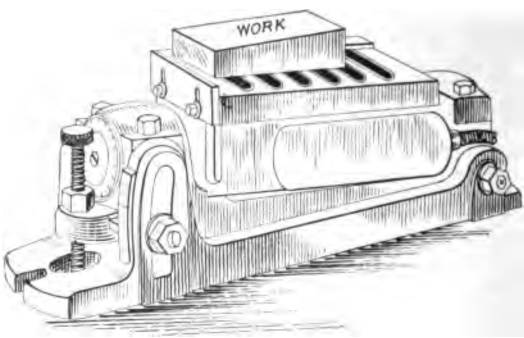


FIG. 276.—Magnetic vise or magnetic chuck.

Made in many sizes and styles, some of which are hinged on the end of a special base and may be provided also with facilities for tipping laterally in either direction. This forms a "universal" vise.

The face of the vise is made up of a number of magnet poles separated by nonmagnetic metal and coils of insulated wire form these into electro-magnets when current is applied.

Rotary magnetic chucks are made for plain grinding machines, etc.

Current can be supplied from any lamp socket on a direct current circuit; *alternating current cannot be used.*

Nothing but iron or steel can be held on the vise.

Do not use water except when vise is made for it.

Do not attempt to take the vise apart.

the revolving grinding wheel. The principles of grinding as discussed in preceding pages apply to surface grinding as well as to any other kind of grinding.

Two types of surface grinding machines are illustrated in Figs. 246 and 247. In the *horizontal spindle machine* the wheel cuts only a very slight amount for each forward and return movement of the table. The table speed is about 20 feet per minute. The cross feed is automatic at each end of the work. In the *vertical spindle machine*, the wheel has a considerably greater contact with the work and the table motion is necessarily much slower.

In either type of machine, the work may be fastened to the table, clamped in a vise or special fixture, or held by means of a magnetic vise, Fig. 276.

FIG. 277.—"Hardened steel, and to a slight degree cast iron, coming in contact with the magnetic chuck, becomes permanently magnetized. On some classes of work this is found objectionable and the apparatus shown is provided for the purpose of demagnetizing the work when necessary. After first setting the demagnetizer in motion, practically all traces of magnetism are removed from the work by simply vibrating it several times in and out of contact with the metal plates at the top. This apparatus consists essentially of a magnet suitably held, and revolving under a mass of laminated sheet iron plates in contact with the two metal plates shown at the top. The phenomenon of demagnetizing may be briefly explained as follows:

"The iron plates at the top of the apparatus represent the poles of a magnet in which the polarity is rapidly reversing. This reversal of polarity is transmitted to the work which is laid in contact. At the moment of reversal, however, there is a neutral point in which for an instant, there is no magnetism. In removing the work out of a strong magnetic field to a weaker one (by lifting it away from the apparatus), it has moved a certain distance during the time that the magnet is neutral and the next time it becomes charged up, being in a weaker field, it does not take so strong a charge as before, and by repetition of this movement, the magnetism is finally removed."
(*O. S. Walker & Co.*)

Work held on a magnetic vise becomes more or less magnetized and while reversing the current by means of a double

switch serves to remove most of the magnetism, the demagnetizer, Fig. 277 is more efficient for this purpose and is recommended. Even with the demagnetizer, total demagnetization does not occur and this is a serious objection on certain classes of work, for example gage work.

In such work the thin pieces that cannot be conveniently held in a vise or otherwise clamped may be held securely by a few drops of wax here and there along the corners between the edge of the work and the table.

It should be understood that when using the magnetic vise for holding small pieces, or for work with a base small in proportion to the height, an abutting piece or back stop of sufficient base and suitable thickness or height should be used to keep the work from slipping or tipping under the pressure of the cut. A piece of sheet steel say $\frac{1}{16} \times 2 \times 6$ in. makes an excellent stop for the smaller pieces, and an angle plate with a base 3 or 4 in. square is very useful to support work that otherwise is likely to tip on the magnetic vise. Often it is best to clamp such work to the angle plate.

Surface grinding calls for patience, it cannot be rushed or heat will be generated on one side and warp the work. One or two thousandths chip with $\frac{1}{16}$ in. feed may be all a thin piece will stand unless provision is made for a flow of water on the work. The wheel should be softer than for the same material in round work because the wheel contact is greater.

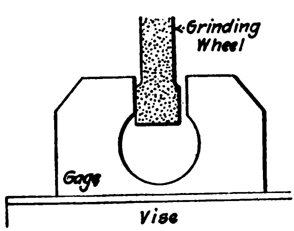


FIG. 278.—Shows a wheel relieved on the sides for "face grinding."

When grinding a shoulder or facing, especially in the surface grinding machine (see Fig. 278, for example) care must be taken to note that there is no end play in the machine spindle and that the bearings are well oiled.

Questions on Grinding 2

1. Can you suggest why a wheel that has been running a few minutes will run smoother and in a slightly different position than when first started?

2. Are you able to tell a sound wheel from a cracked wheel?

3. Make notes of your moves in grinding a cylinder and compare with paragraph 275.

4. Set down the operations in grinding a taper. How do these operations compare with those for grinding a cylinder?

5. What very important precaution must be observed when grinding tapers to size if the automatic cross feed and stop are used?

6. If, when setting up for grinding tapers, the first piece is getting near to *size*, but not quite the right *taper*, why is it advisable to take that piece out and start another.

7. If the piece being ground is, for example, 6 in. taper per foot and does not go far enough in the gage by 1/4 in. how much too large is it?

8. What precaution is necessary when grinding shouldered pieces?

9. Suppose you had to grind a dozen shouldered jig bushings similar to (*b*), Fig. 31 (p. 31), would you set the reversing dogs? Would you use the automatic cross feed?

10. State how you would grind these bushings and why.

11. When grinding an angle by swiveling the wheel head, how is the wheel fed *along* the work?

12. As in above question—how do you feed to take a deeper cut?

13. As in Questions 11 and 12—can either automatic feed be used? Explain.

14. Swivelling the wheel head 45° will grind the work 45° with its center line. Will swivelling the table 30° grind the work 30° with its center line? Make a sketch and expl in this.

15. How may you re-grind the centers of the machine if necessary? Could you hold work in the chuck on the headstock spindle and grind an angle?

16. What is the "face chuck?" What is the purpose of the expansion bushing? How is it expanded?

17. How would you set up to grind a slotting cutter for the milling machine to have it slightly thinner toward the center for clearance?

18. Are you able to set up the internal grinding attachment?

19. What is a bell-mouthed hole? How do you account for a bell-mouth?

20. State two methods of setting up to grind a taper hole.

21. Suppose a piece is clamped too hard or otherwise strained. Is it true when the pressure is released? Explain.

22. What is a magnetic vise?

23. Is a piece 6 in. square more securely held in a magnetic vise than a piece 1 in. square? How are the small pieces kept from slipping?

24. Of what use is an angle plate on a magnetic vise?

CHAPTER XVII

SPUR GEARS AND BEVEL GEARS

284. Introduction.—It is not the purpose of this text to go into the design of gears or gear teeth but merely to give the beginner sufficient information to enable him to understand the terms and rules used in making gears and the application of the rules necessary to turn up a gear blank in a lathe and to form the teeth in a milling machine and know what he is doing.

SPUR GEARS

285. Reason for Gears.—If two rolls as in *a* (Fig. 279) are in close contact and one is turned the other will revolve. The circumference of the driven roll will move as many inches as the circumference of the driving roll moves *if there is no slip,* but the drive of B is dependent upon *friction* with A and only a very light load can be transmitted from A to B.

If, however, the faces of the two rolls are toothed as shown in *b* (Fig. 279) motion may be transmitted positively from A' to B' and as great a load may be transmitted as the strength of the teeth will permit. Rolls or wheels with teeth are called gears. When the rolls are cylindrical in shape with teeth parallel to the axis the gears are called *spur gears* and when the rolls are coneshaped (bevel face) the gears are called *bevel gears.* If positive dependence could be placed upon frictional contact, gears would be unnecessary but as there must invariably be a certain amount of slip when using any kind of drive depending upon the friction of rolls, belts, etc., gearing is used to give a positive definite velocity ratio from one shaft or spindle to another.

To convert rotary gear motion into reciprocating motion, or vice versa, a rack is used. A *rack* is a straight rectangular

strip with teeth formed in the face to mesh with gear teeth of corresponding size (pitch).

286. The pitch circle or "pitch line" of a gear is the line that represents, in drawings and calculations, an imaginary surface corresponding to the original friction surface. The pitch circles of the two gears *A′* and *B′* are shown in *b* (Fig. 279) and it will be noted that they correspond to the friction

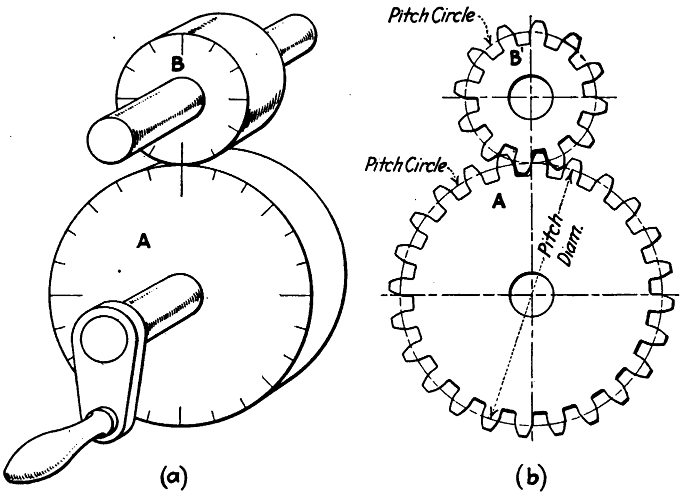


FIG. 279.—(*a*), *B* is half as large as *A* and with no slip will make twice as many turns as *A*. (*b*), The *pitch circle of B′* is half as large as the *pitch circle* of *A′* therefore the gear *B′* will go twice as fast as *A′*.

surfaces of the two rolls *A* and *B* respectively, their diameters being equal. The diameter of the pitch circle of a gear is called the *pitch diameter.*

The circles of the two rolls represent real surfaces; in the gears the pitch lines represent theoretical or imaginary surfaces. However, the pitch circle, or more correctly *the pitch diameter,* is a very important factor in gearing; the relative velocities of the gears in mesh depend upon their *pitch diameters,* not upon their outside diameters, and further, having given the number of teeth, the shape and size of the teeth depend upon the pitch diameter of the gear.

287. Addendum, Dedendum, Etc.—Note in *b* (Fig. 279), that when sizing the gear blanks (outside diameter) they must be made large enough to provide for the part of the tooth above the pitch line; and when milling the grooves they must be cut deep enough below the pitch line to allow the teeth in the mating gear to engage properly.

The depth of a gear tooth from the outside diameter to the pitch line is called *addendum* (Fig. 280).

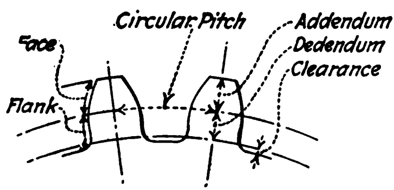


FIG. 280.

The depth of a gear tooth below the pitch line is called the *dedendum*.

Addendum plus dedendum equals the *working depth* of the tooth.

In order that the top of the teeth of one gear shall not rub on the bottoms of the grooves of the mating gear, the grooves are cut deep enough to allow for *clearance*.

The working depth plus the clearance equals the *whole depth*.

The surface of the tooth above the pitch line is called the *face* of the tooth and below the pitch line is called the *flank*.

NOTE.—The surface of a pulley on which the belt runs is called the face of the pulley; so with a gear, the working surface, that is the toothed surface, is called the *face of the gear*. Do not confuse the face of the gear with the face of the tooth.

In order that the relative speeds shall be correct the addenda of mating gears must be the same, and in order that the gear teeth shall transmit motion smoothly they must be properly shaped. How the addendum, working depth, clearance, etc., are calculated will presently be explained; other definitions and explanations are in order first.

288. Circular Pitch.—The distance between the center of one tooth and the center of the next measured on the pitch line is called the *circular pitch*. (In racks it is called the *linear pitch.*) There are as many circular pitches in a gear as there are teeth in that gear.

The term "pitch" is used in machine work, to denote a size.

Before the days of indexing devices, formed cutters and gear cutting machines, most gears were cast gears, the patterns were laid out in the pattern shop, and then the gears were cast and filed more or less to shape. Circular pitch was then used to designate the size of the gear tooth and easily measured pitches such as ¼ in., ½ in., ¾ in., etc., were used. The pattern maker used the circular pitch (or more correctly, he used the chord of the circular pitch or "chordal pitch") to space the teeth in the pattern gears and the calculations for diameter, center distance, etc., were based on circular pitch. Today, however, the circular pitch is used only indirectly in calculations for the reason that a simpler and better system has been devised.

289. Diametral Pitch System.—The circumference of a circle is 3.1416 times the diameter, consequently if either is a simple figure or fraction, the other is a decimal, more or less awkward to handle in calculations. Now there is no question of the value of a gear system in which the *pitch diameters* rather than the pitch circumferences are simple dimensions. Indexing devices have been developed for accurately spacing the teeth and consequently no layout for circular pitch or even chordal pitch is necessary, and further, since the formed tooth cutter will form the teeth within commercial limits of accuracy no layout for the tooth shape is necessary in the shop. Therefore, there being no particular advantage in having the circular pitch an even number or an easily used fraction, and every advantage in having a system which simplifies calculations and measurements, the "Diametrical Pitch System" was devised and is now practically in universal use. This system bases the gear calculations and measurements on the pitch diameter rather than on the circular pitch. By this system the pitch diameters, the center distances between gears, the working depth of teeth, etc., are easily handled figures and fractions.

In the diametral pitch system the pitch diameter is made a convenient dimension let the pitch circumference be what it may. A designer may put any number of teeth desired on a gear of a given diameter, for example, on one gear 2 in. pitch diameter he may put 20 teeth and on another gear, same pitch

diameter he may put 40 teeth. On the 20-tooth gear he will have a larger stronger tooth, on the other the teetb will be half as large but the gear will run more quietly. These gears, of course, will not mesh with each other but either will mesh with a gear having teeth of corresponding size. Note that on one gear (2 in. pitch diameter 20 teeth) there are 10 teeth to each inch of pitch diameter—on the other gear (2 in. pitch diameter 40 teeth) there are 20 teeth to each inch of pitch diameter. In the diametral pitch system the one is a "10-pitch gear" and the other is a "20-pitch gear."

290. The diametral pitch of a gear is the *number* which expresses the number of teeth in that gear for each inch of its pitch diameter. It expresses also the *size* of the gear tooth, as will be explained presently. Diametral pitch is always represented by the letter *P;* circular pitch by *P′* (*P prime*). In gearing whenever the word "pitch" is used alone *diametral* pitch is meant. Perhaps a better idea of diametral pitch may be obtained more quickly if the student understands the module.

291. The Module (in English Measure).—The module (meaning measure) is the same part of the pitch diameter as the circular pitch is of the pitch circumference. That is, if the pitch diameter of a gear is divided into as many equal parts as there are circular pitches (teeth) in the gear, each part will be a definite distance which is called the module. Expressed in still another way module is the pitch diameter in inches divided by the number of teeth in the gear. In a gear, for example 3 in. pitch diameter 30 teeth, the module is $\frac{1}{10}$ in., and in a gear 2 in. pitch diameter 24 teeth, the module is $\frac{1}{12}$ in. In the drawing (Fig. 282), the gear 2 in. pitch diameter 20 teeth has a module of $\frac{1}{10}$ in. and is a $10P$ gear. Note in each case, that the module is a fractional part of an inch and equals one divided by the pitch $\left(\frac{1}{P}\right)$. In other words diametral pitch (P) is the reciprocal of the module. The term module is seldom used in this country, the expression $\frac{1}{P}$ is used instead.[1]

[1] In metric gears module is used and the term diametral pitch is not used (see p. 374).

NOTE.—As a possible means of making clearer the meaning and value of diametral pitch and module this note is added.

The circular pitch is 3.1416 times as large as the module, or the module is $\frac{1}{3.1416}$ as large as the circular pitch. Therefore it is impossible to have both the circular pitch and the module an even number. It is better to have the pitch diameter of gears some common dimension such as 3 in., 3½ in., 4 in., 6 in., 8 in., etc., and to let the circular pitch be what it may, consequently it is common practice when designing cut gears to make the module some nominal part of an inch such as $\frac{1}{12}$ in., ⅛ in., ¼ in., etc. Now these common fractions (modules) could be used in gear calculations but as it is easier to use whole numbers

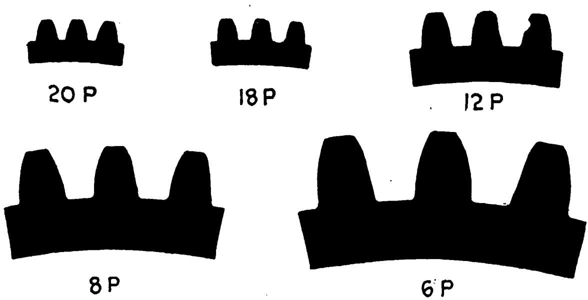


FIG. 281.—Shows relative sizes of gear teeth of five different pitches.

than it is to use fractions the reciprocal of the fraction is used and it is called the *diametral pitch*. For instance it is easier to say "12-pitch gear" than it is to say "$\frac{1}{12}$-inch module gear" and more convenient to express and perform multiplication by 12 than division by $\frac{1}{12}$.

STANDARD VALUES

292. Parts of gear teeth have been named, the sizes have been standardized as for a given pitch, and the Brown & Sharpe notations for gear and gear tooth parts are practically in universal use. These values, definitions and notations should be learned. A page of rules has been included for study and reference.

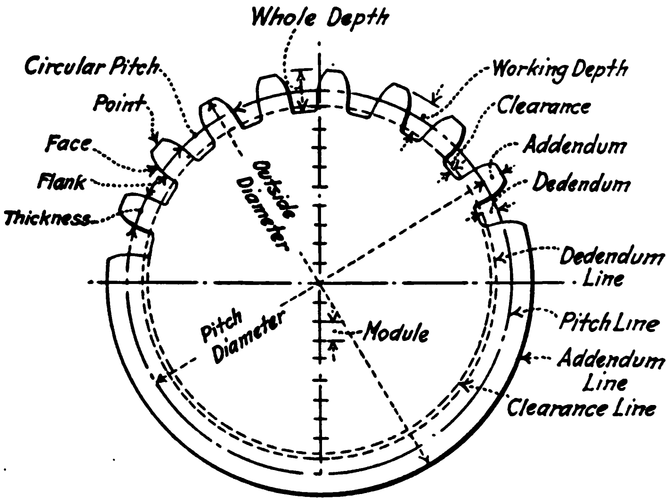


FIG. 282.—Gear elements and tooth parts.

Values of Gear Tooth Parts

Thickness of tooth (on pitch line[1]) equals one-half the circular pitch or in terms of diametral pitch equals one-half of $\frac{3.1416}{P}$ or $\frac{1.57}{P}$.

Addendum is made equal to the module or $\frac{1}{P}$.

Dedendum is also made equal to the module or $\frac{1}{P}$.

Working depth is equal to addendum plus dedendum or $\frac{2}{P}$.

Clearance is made (usually) one-tenth of the thickness of the tooth, that is in terms of diametral pitch one-tenth of $\frac{1.57}{P}$ or $\frac{.157}{P}$.

[1] The difference between the thickness on pitch line and the chordal thickness as measured with a gear tooth caliper is so small as to be usually disregarded in practice.

Whole depth equals working depth $\left(\frac{2}{P}\right)$ plus clearance $\left(\frac{.157}{P}\right)$ or $\frac{2.157}{P}$.

Outside diameter of gear equals pitch diameter plus two addenda (that is, pitch diameter plus two modules) or in terms of diametral pitch, equals pitch diameter plus $\frac{2}{P}$.

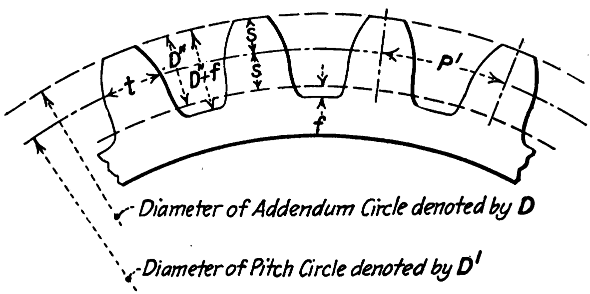


FIG. 283.

293. Standard Notations (B. & S. System) (Fig. 283).

P = diametral pitch (not a distance but a number), the number of teeth to each inch of pitch diameter.

D = the outside diameter of the gear.

D' = diameter of pitch circle (pitch diameter).

P' = circular pitch (on a rack linear pitch).

t = thickness of tooth.

s = module; s = also the addendum; equals also the dedendum.

D'' = working depth of tooth, addendum plus dedendum or $2s$.

f = clearance, extra depth of space below working depth.

$D'' + f$ = whole depth of tooth or tooth space.

N = number of teeth in the gear.

n = number of teeth in mating gear or pinion.

$.3183 = \frac{1}{3.1416}$.

294. Rules and Formulas for Dimensions of Spur Gears made to Diametral Pitch.

To find	Having	Rule	Formula
1. Diametral pitch	Circular pitch	Divide 3.1416 by the circular pitch	$P = \frac{3.1416}{P'}$
2. Diametral pitch	Number of teeth and pitch diameter	Divide number of teeth by pitch diameter	$P = \frac{N}{D'}$
3. Diametral pitch	Number of teeth and outside diameter	Add 2 to the number of teeth and divide by the outside diameter	$P = \frac{N+2}{D}$
4. Circular pitch	Diametral pitch	Divide 3.1416 by the diametral pitch	$P' = \frac{3.1416}{P}$
5. Circular pitch	Pitch diameter and number of teeth	Divide the pitch diameter by the product of .3183 and the number of teeth	$P' = \frac{D'}{.3183N}$
6. Number of teeth	Pitch diameter and diametral pitch	Multiply the pitch diameter by the diametral pitch	$N = D' \times P$
7. Number of teeth	Outside diameter and diametral pitch	Multiply the outside diameter by the diametral pitch and subtract 2	$N = D \times P - 2$
8. Pitch diameter	Number of teeth and diametral pitch	Divide the number of teeth by the diametral pitch	$D' = \frac{N}{P}$
9. Pitch diameter	Outside diameter and addendum	Subtract two times the addendum from the outside diameter	$D' = D - 2s$
10. Outside diameter	Number of teeth and diametral pitch	Add 2 to the number of teeth and divide by the diametral pitch	$D = \frac{N+2}{P}$
11. Outside diameter	Number of teeth and pitch diameter	Add 2 to the number of teeth and divide this sum by the quotient of number of teeth divided by the pitch diameter	$D = \frac{N+2}{\frac{N}{D}}$
12. Outside diameter	Pitch diameter and diametral pitch	Add to the pitch diameter the quotient of 2 divided by the diametral pitch	$D = D' + \frac{2}{P}$
13. Thickness of tooth	Diametral pitch	Divide 1.57 by the diametral pitch	$t = \frac{1.57}{P}$
14. Clearance	Diametral pitch	Divide .157 by the diametral pitch	$f = \frac{.157}{P}$
15. Whole depth of tooth or tooth space	Diametral pitch	Divide 2.157 by the diametral pitch	$D'' + f = \frac{2.157}{P}$
16. Center distance	Pitch diameters	Divide sum of the pitch diameters of the pair of gears by 2	$= \frac{D' + D'}{2}$
17. Center distance	Numbers of teeth and diametral pitch	Add together the numbers of teeth and divide one-half the sum by the diametral pitch	$= \frac{(\frac{1}{2} N + n)}{P}$

295. Shape of Tooth.[1]—To obtain a smooth uniform rolling action of one gear on another of the same pitch (regardless of the sizes) the teeth must be properly shaped. The experience of many years has gradually limited the shape of gear teeth to the involute curve. An involute (Fig. 284), is a curve that would be developed by the end of a string or tape if it were kept taut while being unwound from a cylinder.

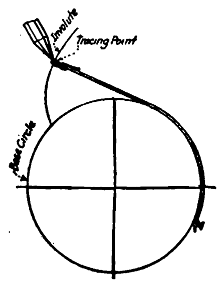


FIG. 284.— Involute curve.

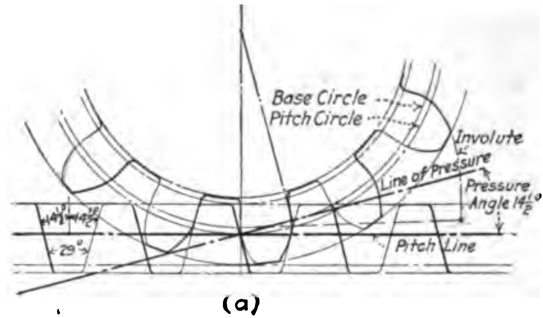
The "base circle" of a gear, (corresponding to the cylinder from which the curve is generated) is somewhat smaller than the pitch circle of the given gear to give the desired "pressure angle" and consequent tooth shape to the gear.[2] The pressure angle (Fig. 285), is the angle at which a tooth on one gear presses a tooth on the mating gear. The pressure angle is measured between the line of the direction of the pressure (called line of action) and the common tangent to both pitch circles.

The pressure angle in most common use is 14½° although a 20° pressure angle is favored in certain classes of work.[3] In either case the side of the *rack tooth* is straight, in the one case 14½° from the perpendicular and in the other 20° from the perpendicular. In any *gear*, however, the shape of the tooth is more or less curved; the smaller the gear of a given pitch the more it curves. In other words, the larger the gear of a given pitch the nearer the tooth approaches the shape of a rack tooth or the nearer straight it becomes. (See Fig. 286.)

[1] The terms "involute," "base circle," "pressure angle" relate more particularly to gear design than to the operation of cutting gears. Those interested in obtaining further information are referred to "Treatise on Gearing," Brown & Sharpe or "The Involute Tooth," Fellows Gear Shaper Co. or "American Machinist Hand Book," etc.

[2] With 14½° pressure angle the diameter of base circle is .968 of pitch diameter; with 20° pressure angle diameter of base circle is .940 of pitch diameter. (Diameter of base circle equals pitch diameter of gear multiplied by cosine of pressure angle).

[3] Discussed later in Par. 298 and 299.



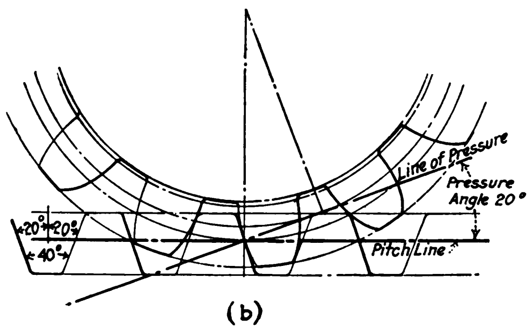


FIG. 285.—Gear and rack (*a*) 14½ degrees pressure angle; (*b*) 20 degrees pressure angle. In both cases the sides of the rack teeth are straight, and the teeth of the gears are of involute shape. Note that the tooth in (*b*) is proportionately shorter; this is a "stub tooth." All parts of all 14½° gear teeth are standard. The parts of the stub tooth gear have not as yet been standardized.

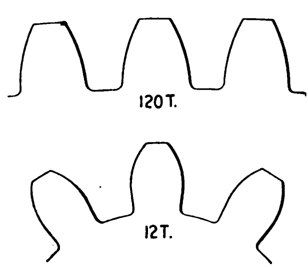


FIG. 286.—Shows portions of two gears of same pitch, 120 teeth and 12 teeth respectively. Note the difference in the shapes of the teeth and also in the grooves between the teeth.

From the foregoing it will be understood that to obtain a continuity of rolling action between the pairs of gear teeth in mesh would require, theoretically, a different tooth curve, a different shape of groove, for each size gear of the same pitch, this difference becoming more pronounced in the smaller gears. However, it has been found by experience,

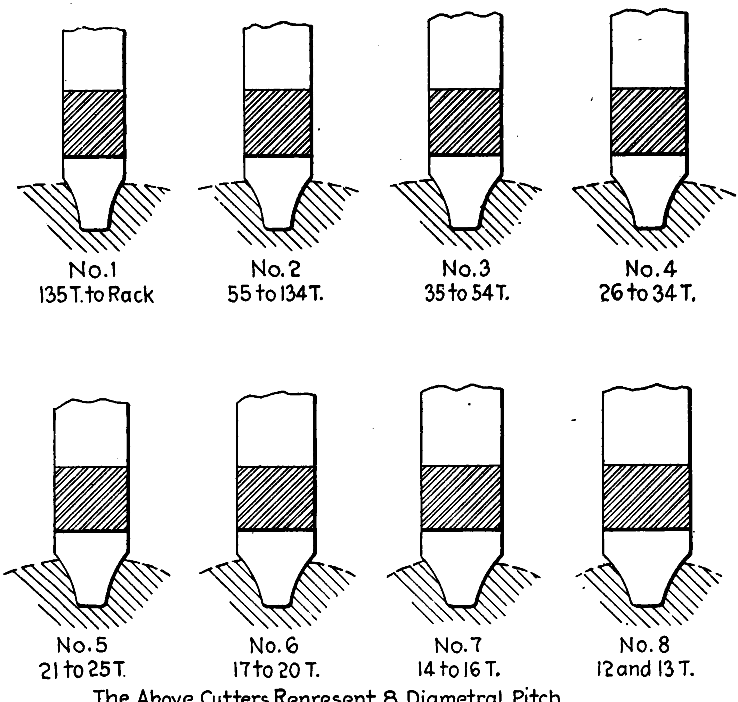


Fig. 287.—Shows variations in a given set of gear cutters.

that a set of eight cutters for each pitch will serve to cut all sizes of gears from 12 teeth to a rack and give commercially satisfactory results. Fig. 287 which represents the cutters for 8*P* illustrates how the curves, the shapes of the teeth, and the shapes of the grooves vary.

296. Gear Cutters.—Cutter manufacturers have generally adopted the following system (originated by Brown & Sharpe Manufacturing Co.) of numbering the cutters for involute gear teeth.

INVOLUTE GEAR CUTTERS (B. & S. SYSTEM)

No. 1 will cut gears from 135 teeth to a rack
No. 2 will cut gears from 55 teeth to 134 teeth
No. 3 will cut gears from 35 teeth to 54 teeth
No. 4 will cut gears from 26 teeth to 34 teeth
No. 5 will cut gears from 21 teeth to 25 teeth
No. 6 will cut gears from 17 teeth to 20 teeth
No. 7 will cut gears from 14 teeth to 16 teeth
No. 8 will cut gears from 12 teeth to 13 teeth

(Cutters made accurate as for the smallest gear in its range)

If a cutter is wanted for a gear of 40 teeth of 8 pitch then the cutter required will be No. 3, 8*P*, inasmuch as a No. 3 cutter will cut all gears containing from 35 to 54 teeth inclusive.

For those who require a finer division of the number of teeth to be cut with each cutter the manufacturers will furnish cutters in half numbers as follows:

Number of cutter	Range	Number of cutter	Range
1½	80 to 134 teeth	5½	19 to 20 teeth
2½	42 to 54 teeth	6½	15 to 16 teeth
3½	30 to 34 teeth	7½	13 teeth
4½	23 to 25 teeth		

297. Metric Gears.—The module (metric measure). In metric gears the sizes are expressed in millimeters, and the dimensions of gear teeth are expressed by reference to the *module.* Diametral pitch is not used because the millimeter being so small a dimension (.03937 in. or about $\frac{1}{25}$ of an inch) modules in whole numbers may be used to designate sizes in common use. For example, a metric gear with a module of

2 mm. (*M* 2 metric gear) is about the same size as a 12*P* gear (exactly 12.7 *P*). Cutters for metric gears, eight for each pitch as in diametral pitch system, are regularly furnished by cutter manufacturers. For further information concerning metric gears see Table 13. Attention is called to the fact that in the formulas given in this table, *M* is the reciprocal of *P* in the formulas given on page 370 for the diametral pitch system.

STUB TOOTH GEARS

298. Values Not Standard.—The involute gear tooth with a 14½° pressure angle made according to the diametral pitch system as described in the preceeding pages is regarded in this country as standard. The metric gears, proportioned exactly the same, the difference in sizes being due to the difference in the units of measurement, (English and Metric) are regarded as standard in the countries using the metric system.

It takes years to establish a "standard" and during this time manufacturers make and sell hundreds and thousands of their own design of, say, tapers, machine keys and gears. For several reasons, some of them no doubt sound reasons, these companies adhere to their sizes, etc., even after a system or standard has been well established. This is a fault if the accepted standard is as good or better than their design but it is nevertheless a condition the machinist has to meet. He can usually meet it more than half way if he has an understanding of the principles involved plus resourcefulness.

There is no doubt about the value of having standards and holding to standards as far as practicable; on the other hand perhaps no standard is the best for all conditions. For example, special tapers, special screws, and special gears, are often better adapted for a given purpose than standard sizes would be. Also new conditions, improved facilities, wider experience, and more thorough investigation may result in new standards.

The automobile is responsible for a new series of thread pitches now generally accepted as the S. A. E. Standard.

The automobile is responsible also for the increased use of the 20° pressure angle gear which seems likely to result eventually in becoming a standard. However, it must be borne in mind that, as yet, there is but one accepted standard in proportioning gear tooth parts and all gears made with teeth proportioned otherwise must be regarded as special.

Special gears require special cutters. These cutters may be obtained from cutter manufacturers or possibly may be already available but in order to duplicate a special gear or to make a gear which will mesh with a special gear requires on the part of the operator or foreman a general knowledge of gear standards and in addition, *certain information concerning that particular gear.* It is impracticable here to give but a hint concerning stub tooth gears but the hint should serve to show first, how essential a knowledge of gear standards is, and second, how necessary it is to measure carefully the special gear to be duplicated or to be mated.

299. Stub Tooth and 20° Pressure Angle.—A gear tooth shaped as for a 20° pressure angle is wider at the base than the 14½° tooth and consequently stronger. The smaller the number of teeth in a gear the more pronounced this difference in shape and strength becomes and for this reason the 20° tooth is especially desirable in gears that are to do heavy work if one or more of the engaging gears is small. Automobile transmission gears afford a good example. It was formerly supposed that a pressure angle greater than 14½° caused undue pressure on the bearings, greater wear on the gear teeth, and more noise, but recent investigation and experience seem to disprove this.

Using the 20° pressure angle permits of using a shorter tooth than standard addendum plus dedendum and most, but *not all*, 20° gears are made with "stub" teeth. Further, various manufacturers of stub tooth gears vary to a considerable extent in tooth shape, that is, there is as yet no *standard* 20° stub tooth gear system. To illustrate this difference the following comparison of standard gear, Nuttall stub gear and Fellows stub gear is made.

Name	Pitch	Working depth	Thickness of tooth	Addendum	Dedendum	Clearance	Whole depth
Standard.........	4	.500	.3297	.250	.250	.039	.539
Nuttall...........	4	.393	.3927	.196	.196	.039	.431
Fellows...........	4/5	.400 same as 5 *P* std.	.3927	.200 same as 5 *P* std.	.200 same as 5 *P* std.	.050	.450

For tables of sizes of tooth parts see pages 415 and 417.

Questions on Spur Gears

1. Watch two engaging gears run. Can you imagine the "original friction surfaces" of the two "pitch cylinders?"

2. Being very careful of your fingers hold a piece of chalk in a position to draw a circle on each one of the revolving gears to represent the surfaces of the two pitch cylinders. What are these circles called?

3. What are the diameters of these circles called?

4. Stop the gears and then turn by hand until a tooth of one gear is exactly between two teeth on the other gear. Note the space between the top of the tooth of the one gear and the bottom of the groove of the other gear. What is this space called?

5. What part of the tooth is the addendum? Dedendum? Working depth? Is the working depth equal to the whole depth? What is it equal to?

6. What is the circular pitch of a gear?

7. What is meant by the module of a gear? In a given gear how much greater is the circular pitch than the module?

8. If a gear is 4 in. pitch diameter, 40 teeth. (1) How many modules in the pitch diameter? (2) How many modules to each inch of pitch diameter? (3) How many teeth in the gear to each inch of pitch diameter? (4) What is the *diametral pitch* of the gear?

9. As you think of a 16 *P* gear do you visualize a tooth about 1/8 in. deep? Do you visualize an 8 *P* gear tooth as about 1/4 in. deep? Explain. Why about 1/8 in. or about 1/4 in. and not exactly 1/8 or 1/4 in.?

10. What is the difference between a "one-quarter-inch module gear" and a "4 pitch gear?"

11. The whole depth of a gear tooth is 2.157 *P*. Explain where you get the 2.157.

It is usually a simple matter to get from a broken gear or a worn gear sufficient information to calculate the sizes for a new gear. The first thing to get is the pitch. In the first calculation the answer may be a fraction but it will be so near a whole number that no doubt this whole number may be taken as the pitch.

12. The outside diameter of an old gear that is to be replaced is $3^{21}/_{32}$ in. scale measurement, and there are 42 teeth on the gear. What is the pitch?

13. What is the exact diameter the new gear should be turned?

14. Suppose you should measure across the diameter of the old gear and find that from the *bottom* of one tooth to the *top* of the opposite tooth was a trifle less than $3\frac{1}{2}$ in. How would you find the pitch?

15. A machinist apprentice had to make two 10 *P* gears 20 teeth and 40 teeth respectively. He turned the blanks to the correct outside diameters. What sizes did he turn them?

16. Then he got a No. 3 cutter 10 *P* from the tool room and cut both gears with this cutter. What mistake did he make?

17. However, the gear was not spoiled. Why not?

18. Certain manufacturers of high grade machine tools advertise "Our spindle driving gears, etc., are cut with special cutters for the particular size and pitch of gear to insure smooth, quiet running." Just what does this mean?

19. Why is the "module" used in calculating metric gears and the diametral pitch in calculating for gears in English measure.

20. What is your understanding of the term "standard" as used in machine shop practice?

21. What differences are usually to be found between the standard tooth and the stub tooth gear.

BEVEL GEARS

300. Introduction.—One should have a working knowledge of the parts and principles of the spur gear before attempting to study the bevel gear. Having this knowledge of spur gears the subject of bevel gears should prove easy to understand if studied step by step in logical sequence. This text is presented in the following order.

1. Preliminary discussion and definitions.
2. Instruction for laying out gears. A layout is advisable to fix in mind certain necessary knowledge as well worth while for the machinist as for the draftsman.
3. Further definitions and instruction.
4. Rules for bevel gear calculations.
5. Examples showing application of the rules. Sizes of gears selected are the same as for layout (2).
6. Cutting a bevel gear in a milling machine.

Do not rush. Try to understand each step before proceeding to the next.

301. Pitch Cylinders and Pitch Cones, Spur Gears and Bevel Gears.—In the same way, as explained in spur gearing, that the motion of one cylinder will cause motion in a parallel cylinder that touches it, motion may be communicated from one shaft to another at an angle to it (whose center lines would meet if sufficiently prolonged) by means of cones in close contact. The apex of each cone is at a point where the center lines of the shafts would meet. Motion may be communicated in the desired velocity ratio (see Fig. 288, *a* and *b*) and at the desired angle (see Fig. 288, *c*, *d* and *e*).

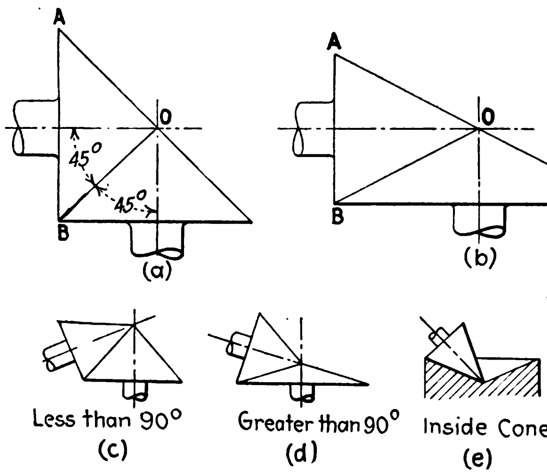


FIG. 288.

In the study of spur gears it was learned that positive motion may be transmitted between parallel shafts by means of spur gears and that spur gears are, in effect, "pitch cylinders" with teeth built on the cylindrical surfaces. Bevel gears are, in effect, "pitch cones" with teeth built on the conical surfaces.

Spur gears communicate motion between parallel shafts. These shafts may be (within limits) any distance apart, and motion may be communicated (within limits) in any desired velocity ratio. Similarly, bevel gears communicate

motion between shafts whose axes meet when prolonged.

In a pair of gears, spur or bevel, the smaller is often called the *pinion*.

Bevel gears are called *miter gears* when they are of the same size and transmit motion at right angles.

302. Pitch Cones.—The cones which represent in bevel gears the original friction surfaces are called the *pitch cones*. It is on frustums (portions at the large end) of these cones that the teeth of bevel gears are built, similarly as the teeth of spur gears are built on the pitch cylinders.

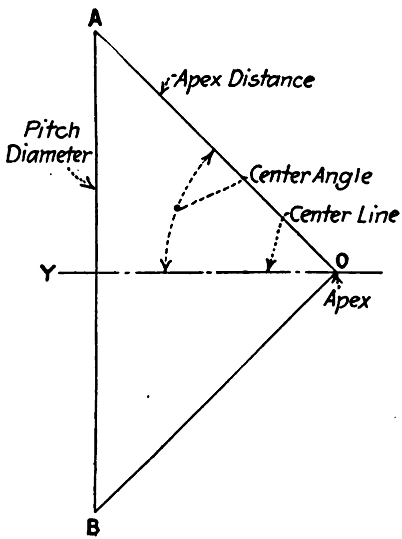


FIG. 289.—Elements of pitch cone. These elements apply to the bevel gear exactly as they apply to the pitch cone.

It is important that one should have a very clear understanding of the elements of the pitch cone; for the reason that although the bevel gear itself is only a portion of a cone, in drawings the whole cone is laid out and in calculations the whole cone is considered.

In the drawing (Fig. 289) the triangle *A O B* represents the pitch cone with the apex at *O*. The line *O Y* is the *center line* (axis) of the cone, and the lines *O A* and *O B* represents the *apex distances*. Either angle *A O Y* or *B O Y* is the *center angle*, sometimes called the *pitch angle*. The line *A B* will equal the *pitch diameter* of the bevel gear built on this one.

303. Center Angle.—In any bevel gear the angle that the capexdistance makes with the center line is called the center angle. Figure 288*a* represents two shafts running at right angles with equal pitch cones. It will be noted that the

center angle is one-half of 90° or 45°. It will be observed in Fig. 288*b* that in right angle bevel gears other than mitre gears the center angle of either the gear or the pinion cannot be 45° and that the center angle depends on the relative pitch diameters of the gear and pinion. The center angle is one of the most important factors in bevel-gear calculations.

304. Pitch Diameter.—When speaking of the pitch diameter of a bevel gear, the diameter at the large end of the pitch cone is meant. As a matter of fact the diameter at any given point in the pitch cone, is the pitch diameter of *that part* of the gear, but in practice no thought or consideration is given to any other pitch diameter than the largest in the gear.

305. Face of Bevel Gear.—In making a bevel gear, the teeth are not cut on the whole pitch cone but only on a portion of it. As the mathematician would say the bevel gear is built on the frustum of a cone or on a truncated cone. The distance equal to the length of the tooth is called the *face* of the bevel gear. The ends of the teeth are spoken of as the "large end" and the "small end."

306. Apex Distance, Tooth Size and Shape.—In any bevel gear of whatever diameter or angle or face, the teeth and spaces are largest at the largest diameter of the gear and decrease in size as the apex of the original pitch cone is approached. If it can be imagined that teeth were cut along the whole pitch cone, half way down the cone the teeth and spaces would be half as large as at the large end and all would vanish at the apex.

Following this reasoning it will be clear that the sizes of bevel gear tooth parts, at the large end and at the small end for example, are proportional to their respective apex distances. This proportion is used in practice, see Rules 4 and 12, page 389.

It will be understood that when the size of the tooth changes the curve of the tooth changes and consequently it will be impossible to cut a bevel gear accurately with a rotary cutter because the cutting edge has a fixed shape and curvature. However a fairly accurate tooth shape can be milled by taking more than one cut, thus "trimming" the tooth as will be explained later.

The drawing (Fig. 290) will serve to illustrate the principle thus far outlined of a bevel gear built on a cone. Let th triangle *A O B* represent the original pitch cone with a cente angle of 45° and a pitch diameter of 3 in. Suppose it is decide to put 30 teeth on this gear and to have the face one-third o the apex distance.[1] The module (gear 3 in. pitch diameter 3 teeth) is 1/10 in. that is, the gea is 10*P*. The apex distance *O* (is two-thirds of the apex dis tance *O A* and consequently th module at the small end of tootl is two-thirds of the module at large end of tooth. That is, al the tooth parts, addendum, dedendum, thickness, at the small end of the tooth will be two-thirds as large as corresponding parts of the tooth at the large end.

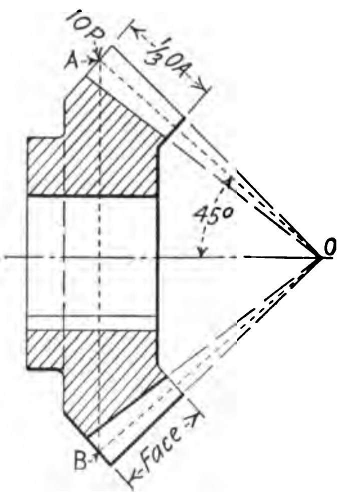


FIG. 290.

307. Laying Out Bevel Gears, Shafts at Right Angles.—Perhaps one of the best methods of becoming acquainted with bevel gear parts and proportions is to lay out first a miter gear, then a gear and pinion. To get parts of miter gears to scale it is only necessary to draw one; to get the angles, proportions, etc., of the gear and pinion it is necessary to lay out both. It is usually best to make the drawings to a large scale if accuracy is required in measurements. In any event, in order to lay our bevel gears it is necessary to know *angle of shafts, relative velocities*, and *pitch of tooth*. Two examples with necessary directions follow (Figs. 291 and 292). Make these drawings full size or larger before proceeding further.

[1] In practice the face of the gear tooth is frequently shorter but never longer than one-third of the apex distance. The dimension should be in sixteenths of an inch or greater, never in thirty-seconds or sixty-fourths.

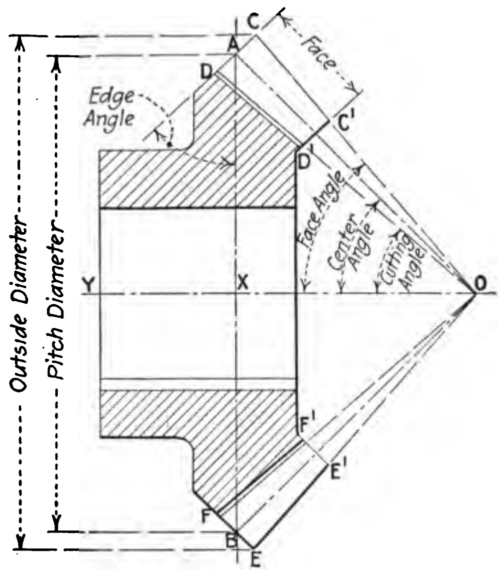


Fig. 291.—Directions for laying out mitre gear. Gear selected 4*P* 20 teeth. Scale halfsize.

1. Draw center line OY and lay off OX equal to one half pitch diameter = $2\frac{1}{2}$ in. ($D' = \frac{N}{P} = \frac{20}{4} = 5$ in.; one half of 5 in. = $2\frac{1}{2}$ in.

2. Through X draw AB perpendicular to OX making AX and BX equal also to one half pitch diameter.

3. Draw OA and OB. These lines give size and shape of cone and each is called the apex distance. Either apex distance with OX forms the *center angle of the gear.* (This gear, and all mitre gears, center angle = 45°.)

4. At points A and B draw lines CD and EF perpendicular to the cone pitch lines OA and OB. These lines form with AB the *angles of edge* or "edge angle." In all bevel gears the angle of edge is equal to the center angle.

5. On line CD lay off points C and D each distant from A equal to the addendum (4P, addendum = $\frac{1}{4}$ in.; $AC = \frac{1}{4}$ in.; $AD = \frac{1}{4}$ in.).

6. Do same at B. ($BE = \frac{1}{4}$; $BF = \frac{1}{4}$ in.)

7. Having decided on the length of face (see foot note, page 382) draw lines $C'D'$ and $E'F'$ parallel to CD and EF respectively.

8. Draw CO and EO. These lines with OX form the *face angles* of the gear.

9. Draw DO and FO. These lines with OX form the *cutting angles* of the gear.

(**Note.**—For clearance see paragraph 313, page 386.)

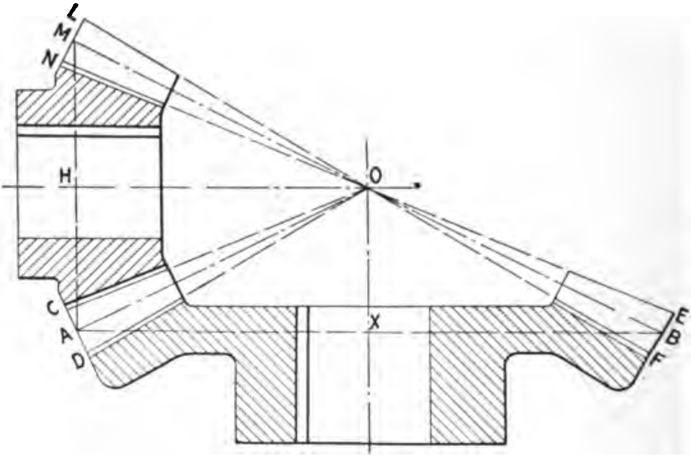


FIG. 292.—Directions for laying out bevel gears. Shafts at right angles. Gears selected. Gear 4*P* 24*T*, pinion, 12*T*. Scale halfsize.

1. Draw center lines of shafts at right angles intersecting at *O*.

2. Lay off *OH* equal to one half pitch diameter of gear (= 3 in.) and lay off *OX* equal to one half pitch diameter of pinion (= 1½ in.).

3. Through points *X* and *H* draw pitch diameters *AB* and *AM* making *BX* = *AX* and *MH* = *AH*.

4. Draw *OA*, *OM*, and *OB*. These lines represent the pitch cones of the 2 gears. The point *O* of intersection of the lines *HO* and *XO* will also be the common point of intersection of all the lines *OL*, *ON*, *OC*, *OD*, *OE*, and *OF*, which are found and drawn same as shown for mitre gears (Fig. 291).

(NOTE.—For clearance see paragraph 313, page 386.)

308. Laying Out Bevel Gears, Shafts Not at Right Angles.—Bevel gears with shafts at other than right angles (Fig. 288, *a* and *b*) may be drawn by method shown in Fig. 292 except that the pitch diameters will not be at right angles to each other.

For example, if the angle of the shafts *H O* and *X O* (as in Fig. 292) were 80° instead of 90°, simply draw pitch diameter *A M* of pinion at an angle of 100° with the pitch diameter *A B* of gear and proceed as for regular bevels. (The smaller the shaft angle the greater the distance *O X*.)

If the shaft angle is 110°, draw the pitch diameter *A M* at an angle of 70° with pitch diameter *A B* and proceed as before.

The angle formed by the two *pitch diameters* will be just as many degrees less than 90° as the shaft angle is over 90°, or just as many degrees over 90° as the shaft angle is less than 90°.

DEFINITIONS OF ANGLES, LINES, ETC.

NOTE.—Rules for obtaining values of the various angles and of the other dimensions are given on page 389.

309. Notations used for parts of bevel-gear teeth—addendum, dedendum, thickness, etc.—and also for certain parts of the gear such as pitch diameter, number of teeth, etc., are the same as for spur gears. There are no standard notations for the construction lines, angles, etc., of the bevel gears, although certain hand books and treatises use various Greek letters to indicate these parts for the purpose of giving formulas. In order not to add to the confusion, rules only have been given here. It should be stated further in this connection that in various places different names are given to the same thing, for instance, the apex distance is often called the cone pitch line, the pitch cone line, or the pitch cone radius. The center angle is often called the pitch angle and the angle of the shafts is termed the center angle. Consequently, when studying reference books take care to avoid mistakes in understanding and in calculations. The terms used in this text are widely used in machine-shop and drawing-room practice.

310. Center Angle, Edge Angle, Face Angle.—For definitions see "Directions for laying out miter gear," Fig. 291.

311. Diameter Increment.—In Fig. 293 (which is a part of Fig. 291 re-drawn for clearness and which may represent any bevel gear) it will be observed that $N\ C$, the outside radius, is greater than $X\ A$, the pitch radius, by the length of $K\ A$ and *not* by the length of $C\ A$ (the addendum). Do not add $\frac{2}{P}$ or "two addendums" to the pitch diameter of a bevel gear to obtain the outside diameter, but *do* add twice the length $K\ A$ to the pitch diameter. This amount ($2\ K\ A$) is called the "Diameter Increment."

312. Angle Increment and Angle Decrement.—It will be noted also (Fig. 293) that in a bevel gear the face angle $X\ O\ C$ is greater than the center angle $X\ O\ A$ by the angle $A\ O\ C$. The angle $A\ O\ C$ is called the "Angle Increment." Also the cutting

angle $X\ O\ D$ is less than the center angle $X\ O\ A$ by the angle $D\ O\ A$. This angle $D\ O\ A$ is called "Angle Decrement." Now since the triangle $C\ O\ A$ and $D\ O\ A$ are right triangles by construction and $C\ A$ equals $A\ D$ (addendum equals dedendum)

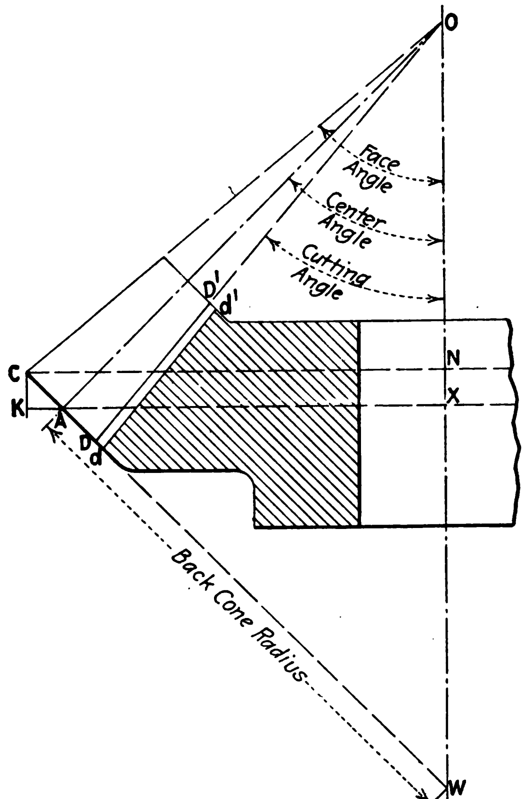


FIG. 293.—Portion of bevel gear.

the triangles are equal and the angle $D\ O\ A$ equals angle $C\ O\ A$ or the angle decrement equals angle increment.

313. The Cutting Angle and the Clearance Cut.—It will be noted further (Fig. 293) that the whole depth of tooth line $d\ d'$ is parallel to DD'. When cutting a bevel gear with

a *rotary cutter*, the clearance as calculated for the large end of the tooth is ordinarily used for the whole length of the tooth. In this case the *cutting angle* equals the center angle minus the angle decrement. When the gear is *planed* the clearance is not of uniform depth but is made proportional to the working depth of the tooth. In this case the cutting angle is made equal to the center angle minus the sum of the angle decrement and the clearance angle (see rules 9 and 10*b*, paragraph 316).

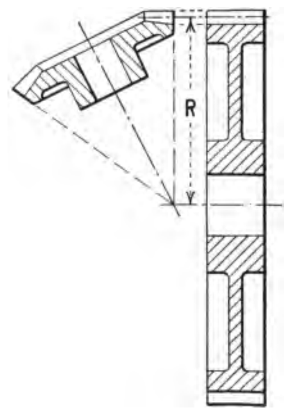


Fig. 294.—Radius of rolling pitch surface.

314. Selecting the Cutter.—In the study of spur gearing it has been learned that the same "form" of gear cutter, that is the same number of cutter, is not used to cut a gear of 20 teeth that is used to cut a gear of 120 teeth. This is because the pitch surface of the 120-tooth gear has a longer radius of curvature than the 20-tooth gear, in other words, it is nearer straight.

Bevel-gear cutters are made in sets similar to spur-gear cutters with the same range of numbers of teeth to each cutter (see p. 374) but bevel-gear cutters are thinner than spur-gear cutters because they must pass through the spaces at the small end of the teeth. There is another feature in the selection of a bevel-gear cutter which at first seems difficult to understand; the cutter is not selected for the number of teeth in the bevel gear itself, but for what might be called a spur gear of corresponding rolling pitch surface. For example, in Fig. 294 the number of cutter to select for the bevel gear would be determined by the number of teeth in the spur gear. The reason for this may be explained as follows:

The radius of the pitch surface of a spur gear is the same as the radius of the pitch circle of that gear, but the radius of the *rolling pitch surface of a bevel gear is longer than the*

radius of the pitch circle of that bevel gear.[1] Thus in Fig. 293 the line $A\ W$ drawn at right angles to the apex distance line $O\ A$ from the pitch point A until it intersects the center line $O\ W$ at W is the *radius* of *curvature* of the pitch surface of the larger end of the gear and is longer than the pitch *radius* $A\ X$. The line $A\ W$ is called the *back cone radius.*

The back cone radius is equal to the pitch radius of a spur gear of corresponding rolling pitch surface, the number of teeth in which will determine the cutter to use to obtain the proper "form" of tooth in the bevel gear (Fig. 294). In other words, twice the back cone radius as measured on a drawing multiplied by the diametral pitch equals the number of teeth for which the cutter should be selected for the bevel gear.

The back cone radius is not used directly in *calculating* the cutter to use (see rule 13, p. 389) but if a good drawing is furnished it may be practically useful in determining the cutter, or in checking the calculation by the rule.

315. Calculations for Bevel-Gear Parts.—The outside diameter, the face angle, the cutting angle, etc. may be obtained fairly close with a scale and protractor from a good drawing. They may be obtained also from tables of gear-tooth parts in hand books, etc. These tables have been calculated by the use of rules and in order to read the tables intelligently it is best to understand the rules.

In order to calculate bevel gears, a working knowledge of some of the functions of right triangles must be had. If

[1] The difference between the curvature of the *rolling pitch surface* of a bevel gear and the curvature of the *pitch circle* of that gear may be easily seen. Select a bevel gear (as large as 10 in. or 12 in. diameter is best) lay a piece of paper along the outer edge of the teeth in close contact against the edge of 5 or 6 teeth and rub it to make an imprint of the teeth on the paper. Trim this paper to the pitch line of these teeth and it will be cut to approximately the *curvature* of the *rolling pitch surface* of the gear. If, now, the paper is held at right angles to the center line of shaft, with the curve cut on the paper as nearly coincident with the curve of the pitch circle of the gear as possible, the difference, between these curves will be apparent. The nearer the bevel gear approaches the spur gear, that is the less bevel it has, the less this difference.

progressive machinists realized how easily and quickly "Shop Trig" may be understood more of them would spend a few hours and get this understanding. Any one of the following books will give the necessary information.

"American Machinists' Hand Book," by Colvin and Stanley. (Published by McGraw-Hill Book Co., N. Y.)

"Mathematics for Machinists," by Burnham. (Published by John Wiley & Sons, N. Y.)

"Shop Mathematics," by Breckenridge, Meserou, and Moore. (Published by Ginn & Co., N. Y.)

"Treatise on Gearing." (Published by Brown & Sharpe M'f'g Co.)

NOTE.—For trigonometric formulas and tables see p. 418 to 423.

316. Rules.—Bevel Gears.

1. *Pitch diameter* equals $\frac{N}{P}$ (same as for spur gears).

2. *Center angle of gear:* Number of teeth in gear divided by number of teeth in pinion equals *tangent* of center angle of gear.

3. *Center angle of pinion:* Number of teeth in pinion divided by number of teeth in gear equals *tangent* of center angle of pinion.

4. *Apex distance* equals pitch radius divided by *sine* of center angle. Apex distance at small end equals apex distance at large end minus the face of gear. (Apex distance same for both gear and pinion).

5. *Diameter increment* equals twice the *cosine* of the center angle divided by the diametral pitch.

5. *Outside diameter* equals pitch diameter plus diameter increment.

7. *Angle increment* (and *angle decrement*): The *tangent* of the angle increment equals twice the *sine* of the center angle divided by the number of teeth. (Angles same for both gear and pinion.)

8. *Face angle* equals center angle plus angle increment.

9. *Clearance angle:* Apex distance divided by the clearance equals *cotangent* of clearance angle. $\left(\text{Clearance equals } \frac{.157}{P}.\right)$

10*a*. *Cutting angle* for milling (see paragraph 313), equals center angle minus angle decrement.

10*b*. *Cutting angle* for bevel-gear planing machine (see paragraph 313), equals center angle minus sum of angle decrement and clearance angle.

11. *Size of tooth parts at large end:* Same as for spur gear of same pitch.

12. *Size of tooth parts at small end:* Divide the apex distance of small end by the apex distance of large end and multiply the respective tooth parts of large end by the quotient.

13. *Number of teeth for which to select cutter* equals number teeth divided by *cosine* of center angle. (NOTE.—Cosine 45° = .707, therefore number of teeth for which to select cutter for miter gear equals number of teeth in miter gear divided by .707.)

317. Example Showing Calculations for Miter Gears.—Gear Selected 4 Pitch—20 Teeth. See Fig. 291. Use Rules (paragraph 316) as indicated by the numbers. (Calculations using rules 3, 9 and 10*b* are unnecessary in this problem.)

1. Pitch diameter $= \frac{N}{P} = \frac{20}{4} = 5''$.

2. Center angle = 45° (45° always in miter gears).

4. Apex distance $= \frac{\text{pitch radius}}{\text{sin cent. ang.}} = \frac{2.5}{.707} = 3.536''$.

5. Diameter increment = 2 times .707 times $\frac{1}{4}''$ = .3535″ (.707 = cosine of the center angle, $\frac{1}{4}''$ = addendum).

6. Outside diameter = 5″ plus .3535″ = 5.3535″.

7. Angle increment. Tan angle increment $= \frac{2(.707)}{20} = .0707$. Now .0707 is tan of angle 4° 3′, therefore angle increment = 4° 3′. (NOTE.—Angle increment in any miter gear is $\frac{81}{N}$, near enough for practical purposes. $\frac{81}{N} = \frac{81}{20} = 4\frac{1}{20}° = 4° 3'$, as above.)

8. Face angle = center angle (45°) plus angle increment (4° 3′) = 49° 3′.

10*a*. Cutting angle = center angle minus angle increment = 40° 57′.

11. Size of tooth parts at large end: $P = 4$, $s = \frac{1}{4}''$, $D'' + f = .539$, $t = .392$.

12. Size of tooth parts at small end: As one-third of apex distance (3.536″) is 1.179″, let face of teeth measure $1\frac{1}{8}''$ or 1.125″. 3.536″ minus 1.125″ = 2.411 equals apex distance of small end of tooth. 2.411 divided by 3.536 = .682. Therefore, multiply all parts of tooth at large end (addendum, thickness, etc.), by .682 to obtain sizes of corresponding tooth parts at small end. $s' = .170$, $t' = .267$.

13. Number of teeth for which to select cutter for miter =

$$\frac{\text{Number teeth}}{.707} = \frac{20}{.707} = 28.$$

(Same form of cutter as for spur gear of 28 teeth. Therefore No. 4 bevel-gear cutter is used. (See paragraph 296.)

318. Example Showing Calculations for Bevel Gears of 12 and 24 T−4 P.—See Fig. 292. Use rules (paragraph 316) as indicated by the numbers. (Calculations using rules 9 and 10*b* are unnecessary in this problem.)

1. Pitch diameter for gear $= \frac{24}{4} = 6$ in. For pinion $= \frac{12}{4} = 3$ in.

2. Center angle for gear: Tan center angle $= \frac{24}{12} = 2 =$ tan of angle of *62° 26′*.

3. Center angle for pinion: Tan center angle $= \frac{12}{24} = .5 =$ tan of angle of *26° 34′*.

4. Apex distance $\frac{\text{pitch radius of gear}}{\text{sin center angle of gear}} = \frac{3''}{.8944} =$ *3.354 in.*

5. Diameter increment for gear: (cos angle 63° 26′ = .4472). $2 \times .4472 \times \frac{1}{4} =$ *.223* = diameter increment for gear.
Diameter increment for pinion: (cos angle 26° 34′ = .8944). $2 \times .8944 \times \frac{1}{4} =$ *.447* = diameter increment for pinion.

6. Outside diameter gear = 6 in. + .223″ = *6.223 in.*
Outside diameter pinion = 3 in. + .447″ = *3.447 in.*

7. Angle increment: Center angle of pinion = 26° 34′. Sine of angle of 26° 34′ = .4472. Then $\frac{2 \times .4472}{12} = .0745 =$ tangent angle increment. .0745 is tangent of *4° 16′*.

8. Face angle *gear* = 63° 26′ + 4° 16′ = *67° 42′*.
Face angle *pinion* = 26° 34′ + 4° 16′ = *30° 50′*.

10*a*. Cutting angle gear = 63° 26′ minus 4° 16′ = 59° 10′.
Cutting angle pinion = 26° 34′ minus 4° 16′ = 22° 18′.

11. Size of tooth parts large end: $P = 4$; $s = \frac{1}{4}$ in.; $D'' + f = .539$; $t = .393$.

12. Size of tooth parts at small end: Let face of tooth equal $1\frac{1}{16}$ in. (1.062). 3.354 minus 1.062 = 2.292. 2.292 divided by 3.354 = .683. Therefore, multiply tooth parts of large end by .683 to obtain corresponding parts on small end. $s = .171$; $t = .268$.

13. *Cutter for gear* $= \frac{\text{number teeth}}{\text{cos center angle}} = \frac{24}{.4472} =$ about 54 or No. 3 bevel-gear cutter.

Cutter for pinion $= \frac{\text{number teeth}}{\text{cos center angle}} = \frac{12}{.8944} =$ about 13 or No. 8 bevel-gear cutter.

319. Cutting a Bevel Gear in a Milling Machine.—As previously stated, it is impossible to cut an *accurate* bevel gear in a milling machine. It often happens, however, that a bevel gear may be wanted in a hurry, or that an extremely

accurate gear is not required, and it is then convenient to know how to mill one (Fig. 295).

FIG. 295.—Cutting a bevel gear in a milling machine.

Bevel-gear cutters have a *curve of cutting edge* that is right for the large end of tooth, and are a trifle *thinner* than the space at the small end.

Let it be required to cut a bevel gear. The following directions in general will apply to any bevel gear, but for sake of clearness select, for an example, a cast-iron gear of 24 *T-4P* (Fig. 292). The data necessary to cut this bevel gear should be furnished with the order or on the drawing, but may be calculated, as previously explained (see rules, paragraph 318). The sizes are as follows:

$$P = 4;\ N = 24;\ D'' + f = .539;\ t = .393;\ s = \tfrac{1}{4}$$

For small end of tooth $t' = .268$; $s' = .171$.
Cutting angle = 59° 10′.
Cutter to use, No. 3.

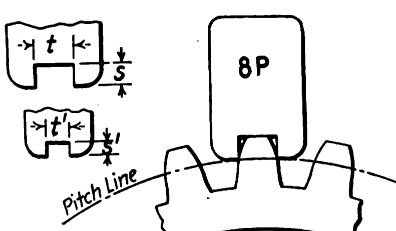


FIG. 296.—Gear tooth gages and illustration of their use. *t*, Thickness at large end; *s*, addendum at large end; *t′*, thickness at small end; *s′*, addendum at small end.

Important Precaution.—In any milling machine indexing operation, the back lash or lost motion in the index head worm and wormwheel, and in the feed screws, is a most serious consideration. **Do not forget the lost motion.**

1. Check the measurements of the blank especially the outside diameter and the face angle.

2. For 24 teeth, set the index pin in a circle divisible by 3. (The largest circle is best to permit of finer adjustment for reasons hereafter explained (10). Set the sector to two-thirds of one turn.

3. Set the dividing head to the cutting angle = 59° 10′.

4. Being careful that spindle, arbor, collars, and cutter are clean and that arbor runs true, set the cutter on the arbor so the direction of the cut will be away from the dividing head spindle. Have the cutter as near the machine spindle as practicable and bring the work *central* under the cutter.

5. Adjust the table until the revolving cutter just touches the gear blank at the *outside* diameter.

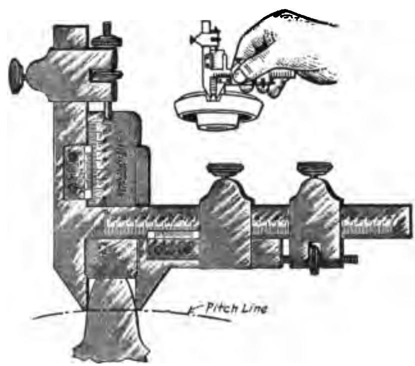


Fig. 297.—Gear tooth vernier. An almost indispensible tool if much gear work is done.

6. Raise the table the distance $D'' + f$ (.539″) and take a cut (perhaps a roughing cut will be advisable). Index for one tooth and take another cut.

7. Measure the thickness of tooth preferably with gear-tooth caliper (Fig. 297) at large end and at small end.

8. Subtract the finished thickness of tooth (t = .393 in. t' = .262) from the thickness as measured, and divide by 2 to know how much must be "trimmed" from each side (Fig. 298). Take *both* halves away and the finished size will remain; take one-half away and the size of tooth *when one side of the tooth is finished* will remain.

Note.—There now are two spaces with a tooth between; the depth of tooth is established and the curve of the cutter is right for the large end, *but* since the thickness of the cutter is about right for the finished space at the small end, the thickness of tooth at the large end is altogether too great. Since the curve of the cutter is correct for the large

end of the tooth, the shape of the tooth at the small end is not right.

The job of cutting a bevel gear in a milling machine is to get the correct *thickness* of tooth, *at the pitch line,* at *both* ends of tooth by trimming both sides of the tooth (*a*, Fig. 298), and then to file the small end to the correct curve (*b*, Fig. 298).

In any motion of a wheel on its axis a point on the rim passes through a greater arc, a greater distance, than a point on the hub. So, by the same principle, in any movement of a bevel gear or bevel-gear blank on its axis, the large end moves

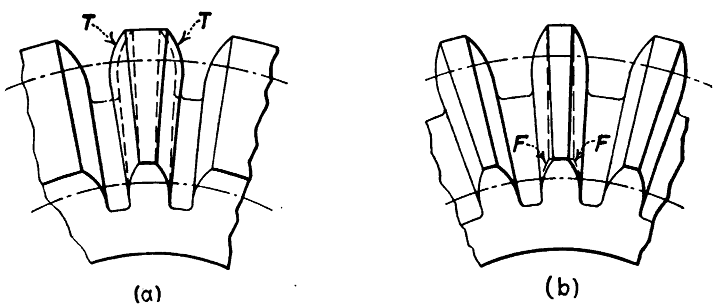


Fig. 298.—(*a*) Shows at *T* where the tooth is trimmed with the cutter; (*b*) shows at *F* where the tooth is filed.

further than the small end. That is, if the gear blank is revolved a very little (if the index pin is removed and advanced one or two holes on the plate) the tooth will be cut thinner, and a little more metal will be removed from the large end than from the small end, *but,* as it happens, *not enough in proportion.* If the gear is rotated say 5 or 6 holes in the 39 circle, the large end may be right; but, the small end will be too thin. To avoid this, off-set the blank, that is, move the table of the milling machine crosswise, bringing the gear tooth *away* from the cutter, and then *rotate* the gear tooth toward the cutter. This has the effect of taking more in proportion off the large end than off the small end.

To continue with the directions:

9. With blue vitriol paint the spaces cut; *take up the lost*

motion in the cross feed screw; set the dial at *O*, and, for a trial, off-set the table about *one-seventh* the thickness of the tooth at the large end.

10. Pull out the index pin and rotate the blank until the large end of the tooth touches the cutter and then *very carefully* (rotating the blank one hole (see 2) in index plate for each cut) trim the side of the tooth until the blue vitriol is nearly all cut off toward the small end.

11. Measure the thickness at the large end, and at the small end for sizes "*when one side is finished*" (see 8). If there yet remains more metal to be cut from the large end than from the small end, the blank must be offset a little more and the tooth trimmed again.

12. Having obtained the position of the blank to trim one side of the tooth for finish, *note the amount of "off-set" and the number of holes which the blank was rotated.*

13. Index for the next tooth, take a cut, and so on all around the gear blank, and there will be 24 teeth with *one side finished.*

NOTE.—In a cast-iron gear of 5 pitch or larger or in a steel gear of 8 pitch or larger, it is usually advisable to take a *central* roughing cut or "stocking" cut before "trimming" either side.

14. Having finished one side of each tooth off-set the gear the same amount from center, being careful about the back lash, *in the opposite direction,* rotate the blank as many holes as noted (see 12) *in the opposite direction,* and carefully checking the measurements of first tooth, (to finished size, see 8) proceed to trim the other side of each tooth.

15. File the small ends of teeth to size.

NOTE.—The amount of offset is from one-seventh to one-sixth of the thickness of the tooth at large end. In the above gear $4\,P - 24T$, it is about .060 in. In a $12P$ $40T$ *miter* gear it is about .018 in. In a pair of bevel gears $8P$, gear $24T$, pinion $12T$, off-set for gear is .030 in. and for pinion is .021 in.

"Too little offset leaves large end too thin."

Questions on Bevel Gears

1. Look up the definitions of the words apex, cone, frustrum, truncated.

2. Explain the following statement: A bevel gear may be said to be built on the frustrum of an imaginary or theoretical cone.

3. Pitch in machine-shop talk means primarily a distance and has come in gear work to denote a given size. In spur gears the teeth are built or "sized" or "pitched" on the pitch cylinder and the teeth of bevel gears are pitched on pitch cones. What do you understand by the pitch cylinder being the working size or effective size of the spur gear and the pitch cone being the working size of the bevel gear?

4. Where is the center line of a bevel gear? The pitch diameter? The apex distance?

5. What is the center angle? Face angle? Edge angle?

6. Is the face angle equal to the center angle? How do the center angle and edge angle compare in size?

7. In shop drawings for turning bevel gears is it necessary to dimension the face angle? What angle does the face of the tooth make with the edge?

8. In order to turn up a bevel gear blank in a lathe is it necessary to know the outside diameter at large end of tooth? At small end?

9. What is the difference between the face of a gear *tooth* and the face of a *gear?*

10. Explain why and how the face of a bevel gear should be dimensioned in a shop drawing.

11. Did you have any particular trouble in laying out the bevel gears?

12. Is the outside diameter of a bevel gear "two addendums larger than the pitch diameter"?

13. What do you understand by diameter increment?

14. Angle increment is sometimes called "addendum angle," and angle decrement the "dedendum angle." Can you explain this?

15. What is the cutting angle? Clearance angle? Is it always necessary to know the clearance angle? Explain.

16. Extreme care must be taken in setting any swivelling device, for example: compound rest in the lathe or dividing head in milling machine, not to cut the compliment of the angle instead of the angle. This is especially true when the angle is only a few degrees more or less than 45°. How do you explain the reason for this precaution?

17. In cutting a miter gear 4 *P* 20 teeth a No. 4 bevel gear cutter marked "26 to 34 teeth" is used (see 13, Paragraph 316). How do you account for this?

18. Do you feel confident that you can intelligently turn a bevel-gear blank and if occasion arises cut it in the milling machine?

APPENDIX

LIST OF TABLES

TABLE 1.—MENSURATION

Area

Parallelogram	= base × perpendicular height.
Trapezoid	= half the sum of the parallel sides × perpendi ular height.
Triangle	= base × half perpendicular height.
Circle	= diameter squared × .7854 or circumferen squared × .07958.
Sector of a circle	= length of arc × half radius.
Segment of a circle	= { area of sector of equal radius—triangle whe segment is less, and + area of triangl when segment is greater than the sem circle.
Side of square of equal area as circle	= diameter × .8862 or circumference × .2821.
Diameter of a circle of equal area as square	= side × 1.1284.
Parabola	= base × ⅔ height.
Ellipse	= long diameter × short diameter × .7854.
Regular polygon	= sum of sides × half perpendicular distanc from center to sides.
Cylinder	= circumference × height + area of both ends.
Sphere	= diameter squared × 3.1416, or diameter × circumference.
Segment of sphere	= height of segment × circumference of spher of which it is a part + area of base.
Pyramid or cone	= circumference of base × ½ slant height + area of base.
Frustum of pyramid	= sum of circumference at both ends × ½ slan height + area of both ends.

Length

Circumference of circle = diameter × 3.1416.
Diameter of circle = circumference × .3183.
Side of square of equal periphery as circle = diameter × .7854.
Diameter of circle of equal periphery as square = side × 1.2732.
Side of an inscribed square = diameter of circle × .7071.
Length of arc = number of degrees × diameter × .008727.
Circumference of circle whose diameter is 1 = 3.14159265.
English statute miles = lineal feet × .00019.
English statute miles = lineal yards × .000568.

TABLE 1.—(*Continued*).

Solid Contents

Prism or cylinder = area of end × length.

Sphere = cube of diameter × .5236.

Segment of sphere = (height squared + three times the square of radius of base) × (height × .5236).

Side of an equal cube = diameter of sphere × .806.

Length of an equal cylinder = diameter of sphere × .6667.

Pyramid or cone = area of base × ⅓ altitude.

Frustum of cone = { add to the product of the two diameters the square of the large diameter and the square of this small diameter; multiply the sum by .7854 and the product by ⅓ the altitude.

TABLE 2.—CUTTING SPEEDS LATHE WORK, DRILLS, MILLING CUTTERS

FORMULAS: $C.S. = .26D \times$ r.p.m. and r.p.m. $= \dfrac{C.S.}{.26D}$

Dia.	Cutting speeds in feet per minute																
	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
	Revolutions per minute																
¼	306	458	611	764	916	1070	1222	1376	1528	1681	1833	1986	2139	2292	2462	2615	2780
⅜	204	306	407	509	612	712	814	916	1019	1120	1222	1324	1426	1528	1632	1735	1836
½	153	229	306	382	458	534	612	688	764	840	917	993	1070	1146	1221	1298	1374
⅝	122	183	244	306	366	428	488	550	611	672	733	794	856	917	976	1036	1098
¾	102	153	204	255	306	356	408	458	509	560	611	662	713	764	816	867	918
⅞	87	131	175	218	262	306	350	392	437	480	524	568	611	655	699	742	786
1	76	115	153	191	230	268	306	344	382	420	458	497	535	573	611	649	687
1⅛	68	102	136	170	204	238	272	306	340	373	407	441	475	509	542	576	610
1¼	61	92	122	153	184	214	244	274	306	336	367	397	428	458	489	520	551
1⅜	56	83	111	139	167	194	222	250	278	306	333	361	389	417	444	472	500
1½	51	76	102	127	152	178	204	228	255	280	306	331	357	382	407	433	458
1⅝	47	71	94	118	141	165	188	212	235	259	282	306	329	353	377	400	423
1¾	44	65	87	109	130	152	174	196	218	240	262	284	306	327	349	371	393
1⅞	41	61	82	102	122	143	163	183	204	224	244	265	285	306	326	346	366
2	38	57	76	95	114	134	152	172	191	210	229	248	267	287	306	324	344
2⅛	36	54	72	90	108	126	144	162	180	198	216	234	252	270	288	306	323
2¼	34	51	68	85	102	119	136	153	170	187	204	221	238	255	272	289	306
2⅜	32	48	64	80	97	112	129	145	161	177	193	210	225	241	257	273	290
2½	31	46	61	76	92	106	122	134	153	168	183	199	214	229	244	260	275
2⅝	29	44	58	73	88	102	117	130	146	160	175	189	204	218	233	248	262
2¾	28	42	56	70	83	97	111	125	139	153	167	181	194	208	222	236	250
2⅞	27	40	53	67	80	93	106	119	133	146	159	173	186	199	213	226	239
3	25	38	51	64	76	90	102	114	127	140	153	166	178	191	204	216	229

TABLE 3.—PLANER CUTTING SPEEDS

Actual number of feet of metal cut per minute with given forward speeds and various return speeds.

Forward Cutting Speed in Feet per Minute	Return Speed						
	2 to 1	3 to 1	4 to 1	5 to 1	6 to 1	7 to 1	8 to 1
20	13.3	15.	16	16.66	17.14	17.5	17.76
25	16.6	18.75	20	20.83	21.42	21.87	22.16
30	20.	22.5	24	25.	25.71	26.25	26.56
35	23.3	26.25	28	29.16	30.	30.62	31.04
40	26.6	30.	32	33.33	34.28	35.	35.52
45	30.	33.75	36	37.5	38.56	39.37	40.
50	33.3	37.5	40	41.66	42.84	43.75	44.48
55	36.6	41.25	44	45.83	47.12	48.12	48.95
60	40.	45.	48	50.	51.42	52.50	53.43
65	43.3	48.75	52	54.16	55.70	56.87	57.91
70	46.6	52.5	56	58.33	60.	61.25	62.3
75	50.	56.25	60	62.5	64.28	66.62	66.71

The table shows clearly that a slight increase in cutting speed is better than high return speed. A 25-foot forward speed at 4 to 1 return is much better than 8 to 1 return with 20-feet forward speed.

Economical planer speeds are given below (Cincinnati Planer Co.).

Cast Iron roughing......40 to 50 ft.; finishing......20 to 25 ft.
Steel casting and wrought iron roughing 30 to 35 ft.; finishing 20 ft.
Bronze and brass...50 to 60 ft.; Machinery steel...30 to 35 ft.

TABLE 4.—DIAGONALS OF HEXAGONS AND SQUARES

Across flats	Across corners		Across flats	Across corners		Across flats	Across corners	
	Hexagon	Squares		Hexagon	Squares		Hexagon	Squares
1/16	.072	.088	1 3/8	1.587	1.944	2 11/16	3.103	3.800
1/8	.144	.177	1 7/16	1.659	2.032	2 3/4	3.175	3.889
3/16	.216	.265	1 1/2	1.732	2.121	2 13/16	3.247	3.979
1/4	.288	.353	1 9/16	1.804	2.209	2 7/8	3.319	4.065
5/16	.360	.441	1 5/8	1.876	2.298	2 15/16	3.391	4.154
3/8	.432	.530	1 11/16	1.948	2.386	3	3.464	4.242
7/16	.505	.618	1 3/4	2.020	2.470	3 1/16	3.536	4.331
1/2	.577	.707	1 13/16	2.092	2.563	3 1/8	3.608	4.419
9/16	.649	.795	1 7/8	2.165	2.651	3 3/16	3.680	4.507
5/8	.721	.883	1 15/16	2.237	2.740	3 1/4	3.752	4.596
11/16	.793	.972	2	2.309	2.828	3 5/16	3.824	4.684
3/4	.865	1.060	2 1/16	2.381	2.916	3 3/8	3.897	4.772
13/16	.938	1.149	2 1/8	2.453	3.005	3 1/2	4.041	4.949
7/8	1.010	1.237	2 3/16	2.525	3.093	3 5/8	4.185	5.126
15/16	1.082	1.325	2 1/4	2.598	3.182	3 3/4	4.330	5.303
1	1.155	1.414	2 5/16	2.670	3.270	3 7/8	4.474	5.480
1 1/16	1.226	1.502	2 3/8	2.742	3.358	4	4.618	5.656
1 1/8	1.299	1.591	2 7/16	2.814	3.447	4 1/8	4.763	5.833
1 3/16	1.371	1.679	2 1/2	2.886	3.535	4 1/4	4.904	6.010
1 1/4	1.443	1.767	2 9/16	2.958	3.623	4 3/8	5.051	6.187
1 5/16	1.515	1.856	2 5/8	3.031	3.712	4 1/2	5.196	6.363

Diagonal of hexagon equals 1.155 times distance across flats.
Diagonal of square equals 1.414 times distance across flats.
Largest square that can be inscribed in circle equals .707 times the diameter.
Largest hexagon that can be inscribed in circle equals .866 times the diameter.
Largest square that can be cut on cylinder = dia. × .707
Largest hexagon that can be cut on cylinder = dia. × .866

TABLE 5.—WEIGHTS OF FLAT BAR STEEL PER LINEAR FOOT

	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2	1 3/4	2	2 1/4	2 1/2	2 3/4	3	3 1/2	4	5	6
1/8	.213	.266	.320	.372	.426	.479	.530	.585	.640	.745	.850	.955	1.07	1.18	1.28	1.49	1.70	2.13	2.56
3/16	.319	.399	.480	.558	.639	.718	.790	.878	.960	1.12	1.28	1.43	1.60	1.76	1.92	2.24	2.55	3.20	3.83
1/4	.425	.533	.640	.743	.852	.958	1.06	1.17	1.28	1.49	1.70	1.91	2.13	2.34	2.56	2.98	3.40	4.26	5.11
5/16	.531	.665	.800	.929	1.06	1.20	1.33	1.46	1.60	1.86	2.13	2.39	2.66	2.92	3.19	3.72	4.25	5.32	6.38
3/8	.638	.798	.960	1.12	1.28	1.43	1.59	1.75	1.91	2.23	2.55	2.87	3.20	3.51	3.83	4.46	5.10	6.40	7.66
7/16	.744	.931	1.12	1.30	1.49	1.67	1.86	2.05	2.23	2.60	2.98	3.35	3.72	4.09	4.46	5.21	5.95	7.44	8.92
1/2	..	1.07	1.28	1.49	1.70	1.91	2.13	2.34	2.55	2.98	3.40	3.83	4.26	4.68	5.10	5.96	6.80	8.52	10.20
9/16	..	1.20	1.44	1.67	1.91	2.15	2.39	2.63	2.87	3.35	3.83	4.30	4.78	5.26	5.74	6.69	7.65	9.56	11.50
5/8	..	..	1.60	1.86	2.12	2.39	2.66	2.92	3.19	3.72	4.26	4.79	5.32	5.86	6.39	7.44	8.52	10.64	12.78
11/16	..	..	1.76	2.04	2.34	2.63	2.92	3.22	3.51	4.09	4.68	5.26	5.84	6.43	7.01	8.18	9.35	11.70	14.00
3/4	..	..	..	2.23	2.55	2.86	3.19	3.50	3.83	4.46	5.10	5.74	6.40	7.02	7.65	8.92	10.20	12.80	15.30
13/16	..	..	..	2.41	2.76	3.11	3.45	3.80	4.14	4.83	5.53	6.22	6.91	7.60	8.29	9.67	11.10	13.80	16.60
7/8	..	..	..	..	2.98	3.34	3.72	4.09	4.46	5.21	5.96	6.70	7.46	8.19	8.94	10.42	11.92	14.92	17.88
15/16	..	..	..	..	3.19	3.59	3.98	4.38	4.78	5.58	6.38	7.17	7.97	8.77	9.56	11.20	12.80	15.90	19.10
1	..	..	..	..	..	3.82	4.25	4.68	5.10	5.96	6.80	7.66	8.52	9.36	10.20	11.92	13.60	17.04	20.40
1 1/8	..	..	..	..	..	..	4.78	5.27	5.74	6.71	7.65	8.61	9.59	10.54	11.48	13.41	15.30	19.17	22.95
1 1/4	..	..	..	..	..	..	..	5.85	6.38	7.45	8.50	9.57	10.65	11.71	12.76	14.90	17.00	21.30	25.61
1 1/2	..	..	..	..	..	..	..	7.02	7.67	8.94	10.20	11.49	12.78	14.04	15.30	17.88	20.40	25.56	30.

TABLE 6.—WEIGHTS OF STEEL AND WROUGHT IRON

Dia. or Distance Across Flats	Steel: Weight per Foot				Iron: Weight per Foot	
	Round	Square	Hexagon	Octagon	Round	Square
1/16	.010	.013	.012	.011	.010	.013
1/8	.042	.053	.046	.044	.041	.052
3/16	.094	.119	.103	.099	.092	.117
1/4	.167	.212	.185	.177	.164	.208
5/16	.261	.333	.288	.277	.256	.326
3/8	.375	.478	.414	.398	.368	.469
7/16	.511	.651	.564	.542	.501	.638
1/2	.667	.850	.737	.708	.654	.833
9/16	.845	1.076	.932	.896	.828	1.055
5/8	1.043	1.328	1.151	1.107	1.023	1.302
11/16	1.262	1.608	1.393	1.331	1.237	1.576
3/4	1.502	1.913	1.658	1.584	1.473	1.875
13/16	1.763	2.245	1.944	1.860	1.728	2.201
7/8	2.044	2.603	2.256	2.156	2.004	2.552
15/16	2.347	2.989	2.591	2.482	2.301	2.930
1	2.670	3.400	2.947	2.817	2.618	3.333
1 1/16	3.014	3.838	3.327	3.182	2.955	3.763
1 1/8	3.379	4.303	3.730	3.568	3.313	4.219
1 3/16	3.766	4.795	4.156	3.977	3.692	4.701
1 1/4	4.173	5.312	4.605	4.407	4.091	5.208
1 5/16	4.600	5.857	5.077	4.858	4.510	5.742
1 3/8	5.049	6.428	5.571	5.331	4.950	6.302
1 7/16	5.518	7.026	6.091	5.827	5.410	6.888
1 1/2	6.008	7.650	6.631	6.344	5.890	7.500
1 9/16	6.520	8.301	7.195	6.905	6.392	8.138
1 5/8	7.051	8.978	7.776	7.446	6.913	8.802
1 11/16	7.604	9.682	8.392	8.027	7.455	9.492
1 3/4	8.178	10.41	9.025	8.635	8.018	10.21
1 13/16	8.773	11.17	9.682	9.264	8.601	10.95
1 7/8	9.388	11.95	10.36	9.918	9.204	11.72
1 15/16	10.02	12.76	11.06	10.58	9.828	12.51
2	10.68	13.60	11.79	11.28	10.47	13.33
2 1/8	12.06	15.35	13.31	12.71	11.82	15.05
2 1/4	13.52	17.22	14.92	14.24	13.25	16.88
2 3/8	15.07	19.18	16.62	15.88	14.77	18.80
2 1/2	16.69	21.25	18.42	17.65	16.36	20.83
2 5/8	18.40	23.43	20.31	19.45	18.04	22.97
2 3/4	20.20	25.71	22.29	21.28	19.80	25.21
2 7/8	22.07	28.10	24.36	23.28	21.64	27.55
3	24.03	30.60	26.53	25.36	23.56	30.00
3 1/8	26.08	33.20	28.78	27.50	25.57	32.55
3 1/4	28.20	35.92	31.10	29.28	27.65	35.21
3 3/8	30.42	38.78	33.57	32.10	29.82	37.97
3 1/2	32.71	41.65	36.10	34.56	32.07	40.83
3 5/8	35.09	44.68	38.73	37.05	34.40	43.80
3 3/4	37.56	47.82	41.45	39.68	36.82	46.88
3 7/8	40.10	51.05	44.26	42.35	39.31	50.05
4	42.73	54.40	47.16	45.12	41.89	53.33

WIRE GAGES AND SHEET METAL GAGES

Considerable confusion exists in regard to the gage numbers or the decimal equivalent of the gage numbers when ordering wires and sheets of the various metals, owing to the fact that there are so many gages listed in the tables given in handbooks, catalogues, text books, etc. Fortunately most of these older standards are obsolete or practically obsolete and only a few are now generally accepted and used in the trade. These are listed in Table 7.

Steel Wire Gage, formerly called the Washburn & Moen Gage, and also the American Steel & Wire Co. Steel Wire Gage, is the standard gage for steel and iron wire excepting music wire, see "Music Wire Gage," and drill rods, see "Stubs' Steel Wire Gage."

The American Wire Gage, also known as the *Brown & Sharpe* gage, is the generally accepted standard for copper wire (other than telephone and telegraph wire, see British Imperial Standard Wire Gage), brass wire, german silver wire, and also for the thickness of *sheets* of these materials.

The A. S. & W. Co. New Music Wire Gage is regarded as standard in the United States, the older Washburn & Moen Music Wire Gage being obsolete. Foreign music wires are sized according to the respective makers gages.

Music steel spring wire or "music wire" or "piano wire" is the best quality of steel wire and has, as noted, its own particular gage. Nos. 13 to 27 inclusive are used in pianos, some of the smaller sizes in other musical instruments. It is a tough wire of great tensile strength and resilience without extreme hardness. It is particularly useful for making springs since it does not have to be hardened and tempered. Do not confuse music wire with spring wire. *Spring Wire* is made to the Steel Wire Gage. It may be obtained with any desired carbon content for the purpose desired but is not as high grade as music steel spring wire.

The Stubs' Steel Wire Gage is commonly used in this country as well as in England for measuring drill rods. Do not get the Birmingham or Stubs' Iron Wire Gage confused with Stubs' Steel Wire Gage.

The Birmingham or *Stubs' Iron Wire Gage* (B. W. gage) was formerly used in the United States and in Great Britain to designate soft steel and iron wire. It is the gage used for iron telephone and telegraph wire, but for gaging other iron and steel wire, has been superseded to a great extent in Great Britain by the British Imperial Gage and in the United States by the Steel Wire Gage.

British Imperial Standard Wire Gage is now the standard gage of Great Britain. It is used by the American Telephone and Telegraph Co. as a gage for copper telephone and telegraph wire and is referred to as the New British Standard (N. B. Std.).

RESUMÉ

WIRES:

For steel wire, use Steel Wire Gage.

For copper telephone or telegraph wire, use British Imperial Standard Gage. For iron telephone or telegraph wire use Birmingham gage.

For copper, brass, and german silver wire, use American (Brown & Sharpe) gage.

For music wire use A. S. & W. *new* Music Wire Gage, and for imported music wire use gage of maker.

For drill rod use Stubs' Steel Wire gage.

SHEETS:

For iron and steel sheets and plates use United States Standard Gage.

For sheet copper, brass and german silver, use American (Brown & Sharpe) gage.

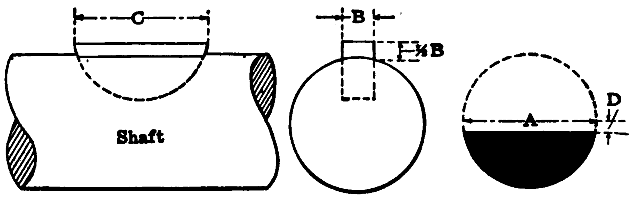
NOTE.—When ordering, it is always well to give the decimal equivalent of the gage size and also the limits plus or minus, that will be acceptable.

Table 7.—Different Standards for Wire Gages and Sheet Metal Gages in Use in the United States

Dimensions of sizes in decimal parts of an inch

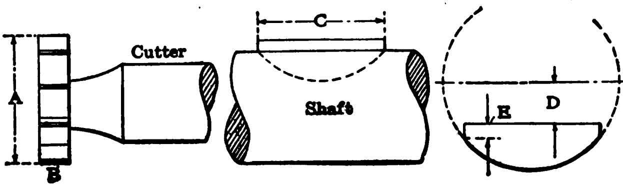
Gage numbers	Steel wire gage	American or Brown & Sharpe gage	American S. & W. Co. *new* music wire gage	Stubs' *steel* wire gage	Birmingham or Stubs' *iron* wire gage	British Imperial Standard wire gage	U. S. Standard gage for sheet and plate iron and steel	Gage numbers
6/0	.4615	.5800	.004	....	....	.464	.4687	6/0
5/0	.4305	.5165	.005	....	.500	.432	.4375	5/0
4/0	.3938	.4600	.006	....	.454	.400	.4062	4/0
3/0	.3625	.4096	.007	....	.425	.372	.375	3/0
2/0	.3310	.3648	.008	....	.380	.348	.3437	2/0
1/0	.3065	.3249	.009	....	.340	.324	.3125	1/0
1	.2830	.2893	.010	.227	.300	.300	.2812	1
2	.2625	.2576	.011	.219	.284	.276	.2656	2
3	.2437	.2294	.012	.212	.259	.252	.25	3
4	.2253	.2043	.013	.207	.238	.232	.2344	4
5	.2070	.1819	.014	.204	.220	.212	.2187	5
6	.1920	.1620	.016	.201	.203	.192	.2031	6
7	.1770	.1442	.018	.199	.180	.176	.1875	7
8	.1620	.1285	.020	.197	.165	.160	.1719	8
9	.1483	.1144	.022	.194	.148	.144	.1562	9
10	.1350	.1019	.024	.191	.134	.128	.1406	10
11	.1205	.0907	.026	.188	.120	.116	.125	11
12	.1055	.0808	.029	.185	.109	.104	.1094	12
13	.0915	.0720	.031	.182	.095	.092	.0937	13
14	.0800	.0641	.033	.180	.083	.080	.0781	14
15	.0720	.0571	.035	.178	.072	.072	.0703	15
16	.0625	.0508	.037	.175	.065	.064	.0625	16
17	.0540	.0452	.039	.172	.058	.056	.05625	17
18	.0475	.0403	.041	.168	.049	.048	.05	18
19	.0410	.0359	.043	.164	.042	.040	.04375	19
20	.0348	.032	.045	.161	.035	.036	.0375	20
21	.0317	.0285	.047	.157	.032	.032	.03437	21
22	.0286	.0253	.049	.155	.028	.028	.03125	22
23	.0258	.0226	.051	.153	.025	.024	.02812	23
24	.0230	.0201	.055	.151	.022	.022	.025	24
25	.0204	.0179	.059	.148	.020	.020	.02187	25
26	.0181	.0159	.063	.146	.018	.018	.01875	26
27	.0173	.0142	.067	.143	.016	.0164	.01718	27
28	.0162	.0126	.071	.139	.014	.0149	.01562	28
29	.0150	.0113	.075	.134	.013	.0136	.01406	29
30	.0140	.01	.080	.127	.012	.0124	.0125	30
31	.0132	.0089	.085	.120	.010	.0116	.01093	31
32	.0128	.00795	.090	.115	.009	.0108	.01015	32
33	.0118	.00708	.095	.112	.008	.0100	.00937	33
34	.0104	.0063	.100	.110	.007	.0092	.00859	34
35	.0095	.0056	.106	.108	.005	.0084	.00781	35
36	.0090	.005	.112	.106	.004	.0076	.00703	36
37	.0085	.00445	.118	.103	....	.0068	.00664	37
38	.0080	.00396	.124	.101	....	.0060	.00625	38
39	.0075	.00353	.130	.099	....	.0052	......	39
40	.0070	.00314	.138	.097	....	.0048	......	40
41	.0066	.00280	....	.095	....	.0044	......	41
42	.0062	.00249	....	.092	....	.0040	......	42
43	.0060	.00222	....	.088	....	.0036	......	43
44	.0058	.00198	....	.085	....	.0032	......	44
45	.0055	.00176	....	.081	....	.0028	......	45
46	.0052	.00157	....	.079	....	.0024	......	46
47	.0050	.00140	....	.077	....	.0020	......	47
48	.0048	.00124	....	.075	....	.0016	......	48
49	.0046	.000986	....	.072	....	.0012	......	49
50	.0044	.000878	....	.069	....	.001	......	50

TABLE 8.—WHITNEY KEYS AND CUTTERS



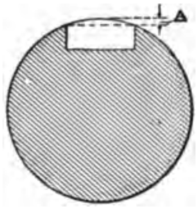
No. of Key and Cutter	Dia. of Cutter	Thickness of Key and Cutter	Length of Key	Key Cut Below Center	No. of Key and Cutter	Dia. of Cutter	Thickness of Key and Cutter	Length of Key	Key Cut Below Center
	A	B	C	D		A	B	C	D
1	$\frac{1}{2}$	$\frac{1}{16}$	$\frac{1}{2}$	$\frac{3}{64}$	16	$1\frac{1}{8}$	$\frac{3}{16}$	$1\frac{1}{8}$	$\frac{5}{64}$
2	$\frac{1}{2}$	$\frac{3}{32}$	$\frac{1}{2}$	$\frac{3}{64}$	17	$1\frac{1}{8}$	$\frac{7}{32}$	$1\frac{1}{8}$	$\frac{5}{64}$
3	$\frac{1}{2}$	$\frac{1}{8}$	$\frac{1}{2}$	$\frac{3}{64}$	18	$1\frac{1}{8}$	$\frac{1}{4}$	$1\frac{1}{8}$	$\frac{5}{64}$
4	$\frac{5}{8}$	$\frac{3}{32}$	$\frac{5}{8}$	$\frac{1}{16}$	C	$1\frac{1}{8}$	$\frac{5}{16}$	$1\frac{1}{8}$	$\frac{5}{64}$
5	$\frac{5}{8}$	$\frac{1}{8}$	$\frac{5}{8}$	$\frac{1}{16}$	19	$1\frac{1}{4}$	$\frac{3}{16}$	$1\frac{1}{4}$	$\frac{5}{64}$
6	$\frac{5}{8}$	$\frac{5}{32}$	$\frac{5}{8}$	$\frac{1}{16}$	20	$1\frac{1}{4}$	$\frac{7}{32}$	$1\frac{1}{4}$	$\frac{5}{64}$
7	$\frac{3}{4}$	$\frac{1}{8}$	$\frac{3}{4}$	$\frac{1}{16}$	21	$1\frac{1}{4}$	$\frac{1}{4}$	$1\frac{1}{4}$	$\frac{5}{64}$
8	$\frac{3}{4}$	$\frac{5}{32}$	$\frac{3}{4}$	$\frac{1}{16}$	D	$1\frac{1}{4}$	$\frac{5}{16}$	$1\frac{1}{4}$	$\frac{5}{64}$
9	$\frac{3}{4}$	$\frac{3}{16}$	$\frac{3}{4}$	$\frac{1}{16}$	E	$1\frac{1}{4}$	$\frac{3}{8}$	$1\frac{1}{4}$	$\frac{5}{64}$
10	$\frac{7}{8}$	$\frac{5}{32}$	$\frac{7}{8}$	$\frac{1}{16}$	22	$1\frac{3}{8}$	$\frac{1}{4}$	$1\frac{3}{8}$	$\frac{3}{32}$
11	$\frac{7}{8}$	$\frac{3}{16}$	$\frac{7}{8}$	$\frac{1}{16}$	23	$1\frac{3}{8}$	$\frac{5}{16}$	$1\frac{3}{8}$	$\frac{3}{32}$
12	$\frac{7}{8}$	$\frac{7}{32}$	$\frac{7}{8}$	$\frac{1}{16}$	F	$1\frac{3}{8}$	$\frac{3}{8}$	$1\frac{3}{8}$	$\frac{3}{32}$
A	$\frac{7}{8}$	$\frac{1}{4}$	$\frac{7}{8}$	$\frac{1}{16}$	24	$1\frac{1}{2}$	$\frac{1}{4}$	$1\frac{1}{2}$	$\frac{7}{64}$
13	1	$\frac{3}{16}$	1	$\frac{1}{16}$	25	$1\frac{1}{2}$	$\frac{5}{16}$	$1\frac{1}{2}$	$\frac{7}{64}$
14	1	$\frac{7}{32}$	1	$\frac{1}{16}$	G	$1\frac{1}{2}$	$\frac{3}{8}$	$1\frac{1}{2}$	$\frac{7}{64}$
15	1	$\frac{1}{4}$	1	$\frac{1}{16}$					
B	1	$\frac{5}{16}$	1	$\frac{1}{16}$					

TABLE 8.—(*Continued*).



No. of Key and Cutter	Dia. of Cutter A	Thickness of Key and Cutter B	Length of Key C	Key Cut Below Center D	Flat at End of Key E	No. of Key and Cutter	Dia. of Cutter A	Thickness of Key and Cutter B	Length of Key C	Key Cut Below Center D	Flat at End of Key E
26	$2\frac{1}{8}$	$\frac{3}{16}$	$1\frac{23}{32}$	$\frac{17}{32}$	$\frac{3}{32}$	30	$3\frac{1}{2}$	$\frac{3}{8}$	$2\frac{7}{8}$	$1\frac{3}{16}$	$\frac{3}{16}$
27	$2\frac{1}{8}$	$\frac{1}{4}$	$1\frac{23}{32}$	$\frac{17}{32}$	$\frac{3}{32}$	31	$3\frac{1}{2}$	$\frac{7}{16}$	$2\frac{7}{8}$	$1\frac{3}{16}$	$\frac{3}{16}$
28	$2\frac{1}{8}$	$\frac{5}{16}$	$1\frac{23}{32}$	$\frac{17}{32}$	$\frac{3}{32}$	32	$3\frac{1}{2}$	$\frac{1}{2}$	$2\frac{7}{8}$	$1\frac{3}{16}$	$\frac{3}{16}$
29	$2\frac{1}{8}$	$\frac{3}{8}$	$1\frac{23}{32}$	$\frac{17}{32}$	$\frac{3}{32}$	33	$3\frac{1}{2}$	$\frac{9}{16}$	$2\frac{7}{8}$	$1\frac{3}{16}$	$\frac{3}{16}$
R	$2\frac{3}{4}$	$\frac{1}{4}$	$2\frac{5}{16}$	$\frac{5}{8}$	$\frac{1}{8}$	34	$3\frac{1}{2}$	$\frac{5}{8}$	$2\frac{7}{8}$	$1\frac{3}{16}$	$\frac{3}{16}$
S	$2\frac{3}{4}$	$\frac{5}{16}$	$2\frac{5}{16}$	$\frac{5}{8}$	$\frac{1}{8}$	35	$3\frac{1}{2}$	$\frac{11}{16}$	$2\frac{7}{8}$	$1\frac{3}{16}$	$\frac{3}{16}$
T	$2\frac{3}{4}$	$\frac{3}{8}$	$2\frac{5}{16}$	$\frac{5}{8}$	$\frac{1}{8}$	36	$3\frac{1}{2}$	$\frac{3}{4}$	$2\frac{7}{8}$	$1\frac{3}{16}$	$\frac{3}{16}$
U	$2\frac{3}{4}$	$\frac{7}{16}$	$2\frac{5}{16}$	$\frac{5}{8}$	$\frac{1}{8}$						
V	$2\frac{3}{4}$	$\frac{1}{2}$	$2\frac{5}{16}$	$\frac{5}{8}$	$\frac{1}{8}$						

TABLE 9.—FINDING TOTAL KEYWAY DEPTH



In the column marked "Size of Shaft" find the number representing the size; then to the right find the column representing the keyway to be cut and the decimal there is the distance *A*, which added to the depth of the keyway will give the total depth from the point where the cutter first begins to cut.

Size of Shaft	1/8 Keyway	3/16 Keyway	1/4 Keyway	5/16 Keyway	3/8 Keyway
1/2	0.0325	....	....	....	....
9/16	0.0289	....	....	....	....
5/8	0.0254	0.0413	....	....	....
11/16	0.0236	0.0379	....	....	....
3/4	0.022	0.0346	0.0511	....	....
13/16	0.0198	0.0314	0.0465	....	....
7/8	0.0177	0.0283	0.042	0.0583	....
15/16	0.0164	0.0264	0.0392	0.0544	....
1	0.0152	0.0246	0.0365	0.0506	0.067
1 1/16	0.0143	0.0228	0.0342	0.0476	0.0625
1 1/8	0.0136	0.021	0.0319	0.0446	0.0581
1 3/16	0.0131	0.0204	0.0304	0.0421	0.0551
1 1/4	0.0127	0.0198	0.029	0.0397	0.0522
1 5/16	0.0123	0.0191	0.0279	0.038	0.0499
1 3/8	0.012	0.0185	0.0268	0.0364	0.0477
1 7/16	0.0114	0.0174	0.0254	0.0346	0.0453
1 1/2	0.011	0.0164	0.024	0.0328	0.0429
1 9/16	0.0107	0.0158	0.0231	0.0309	0.0412
1 5/8	0.0105	0.0153	0.0221	0.0291	0.0395
1 11/16	0.0102	0.0147	0.0214	0.0282	0.0383
1 3/4	0.0099	0.0142	0.0207	0.0274	0.0371
1 13/16	0.0095	0.0136	0.0198	0.0265	0.0355
1 7/8	0.0093	0.013	0.019	0.0257	0.0339
1 15/16	0.009	0.0127	0.0184	0.025	0.0328
2	0.0088	0.0124	0.0179	0.0243	0.0317
2 1/16	0.0083	0.0117	0.0173	0.0236	0.0308
2 1/8	0.0078	0.0111	0.0168	0.0229	0.0299
2 3/16	0.0073	0.0109	0.0163	0.0222	0.0291
2 1/4	0.007	0.0107	0.0159	0.0216	0.0282

For larger sizes see American Machinists' Hand Book

TABLE 10.—INDEX TABLE FOR FLUTING REAMERS WITH UNEQUAL SPACING

Number of flutes	Index circle	Regular indexing	1st index[1]	2d index	3d index	4th index	5th index	6th index	7th index	8th index
6	39	6 turns + 26 holes	Regular	Reg. + 15 holes	Reg. − 15 holes	See foot	note.[2]			
8	39	5 turns	Regular	Reg. + 15 holes	Reg. − 10 holes	Reg. − 5 holes	See	Fig. 224,	p. 262	
10	39	4 turns	Regular	Reg. − 5 holes	Reg. + 10 holes	Reg. + 5 holes	Reg. − 10 holes			
12	39	3 turns + 13 holes	Regular	Reg. − 7 holes	Reg. + 2 holes	Reg. − 10 holes	Reg. + 6 holes	Reg. + 9 holes		
14	49	2 turns + 42 holes	Regular	Reg. − 7 holes	Reg. + 4 holes	Reg. − 9 holes	Reg. + 6 holes	Reg. + 10 holes	Reg. − 4 holes	
16	20	2 turns + 10 holes	Regular	Reg. − 4 holes	Reg. + 2 holes	Reg. − 3 holes	Reg. + 4 holes	Reg. + 2 holes	Reg. − 4 holes	Reg. + 3 holes

[1] One groove to be cut before 1st indexing operation.

[2] Remaining half of number of grooves on all reamers will be cut like first half, beginning "1st index."

Courtesy Brown & Sharpe Mfg. Co.

This table gives grades as listed by the following manufacturers:

American Emery Wheel Works.	Abrasive Materials Company.
Norton Company.	Vitrified Wheel Company.
Carborundum Company.	Monarch Grinding Wheel Company.
Sterling Emery Wheel Mfg. Co.	Safety Emery Wheel Company.

American Emery Wheel Works', Norton Company's, Carborundum Company's and Abrasive Materials Company's grade *M* vitrified wheels are all of about the same degree of hardness. The equivalent in Sterling Emery Wheel Mfg. Company's and Monarch Grinding Wheel Company's vitrified wheels is about grade 2¾ and in the Vitrified Wheel Company's wheels is about grade *E*.

Table 11.—Table of Grinding Wheel Grades

American Emery Wheel Works' Method

	Vitrified wheels	Silicate wheels	Elastic wheels
Very soft	G	½	½E
	H	¾	¾E
	I	1	1 E
Soft			1¼E
	J	1½	1½E
	K	2	1¾E
	L	2½	2 E
			2¼E
Medium	M	3	2½E
	N	3½	3½E
	O	4	4 E
Medium hard	P	4½	4½E
	Q	5	5 E
	R	6	6 E
Very hard	S	7	7 E
	T		
	U		
Extra hard	V		
	W		
	Z		

TABLE 11.—(*Continued*).

Norton Company's Method

Vitrified and silicate wheels

Soft	E, F, G, H	Medium hard	Q, R, S, T
Medium soft	I, J, K, L	Hard	U, W
Medium	M, N, O, P	Extremely hard	Z

Elastic wheels are graded as follows: 1, 1½, 2, 2½, 3, 4 and 5. Grade 1 is the softest and grade 5, the hardest.

Carborundum Company's Method

Vitrified carborundum and aloxite wheels, and silicate aloxite wheels

Very hard	D, E, F, Gx	Medium	M, N, O
Hard	G, Hx, H, Ix	Medium soft	P, R, S
Medium hard	I, J, K, L	Soft	T, U, V
		Very soft	W, X
		Very, very soft	Y and Z

Elastic wheels are graded as follows: ½, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12. Grade ½ is very hard and grade 12 is very, very soft.

TABLE 11.—(*Continued*).

Sterling Emery Wheel Mfg. Company's Method

Vitrified and silicate wheels			
Very soft	1¼, 1½, 1¾	Medium	3, 3¼
Soft	2, 2¼	Medium hard	3½, 3¾
Medium soft	2½, 2¾	Hard	4, 5
		Very hard	6

Elastic wheels are graded as follows: 1, 2, 3, 3½, 4, 4½, 5 and 6 Grade 1 is the softest and grade 6 is the hardest.

Abrasive Material Company's Method

Vitrified and silicate wheels			
Very soft	G, H, I, J	Hard	R, S
Soft	K, L, M	Very hard	T, U, V, W, X, Y
Medium	N, O	Extremely hard	Z
Medium hard	P, Q		

Elastic wheels			
Soft	1, 1½, 2	Hard	5, 6
Medium	2½, 3, 4	Very hard	7

TABLE 11.—(*Continued*).

Vitrified Wheel Company's Method

	Vitrified and silicate wheels	Elastic wheels
Soft	C	½E
	C^1	1 E
	C^2	1½E
	C^3	2 E
Medium soft	D	2½E
	D^1	3 E
	D^2	3½E
	D^3	4 E
Medium	E	4½E
	E^1	5 E
	E^2	5½E
	E^3	6 E
Hard	F	6½E
	F^1	7 E
	F^2	
	F^3	
Extremely hard	G	

Monarch Grinding Wheel Company's Method

	Vitrified wheels	Silicate wheels	Elastic wheels
Very soft	1½		
	1¾	¾	A
Soft	2	1	F
	2¼	1¼	I
	2½	1½	N
	2¾	1¾	E
Medium	3	2	P
	3¼	2¼	R
	3½	2½	O
Hard	3¾	3	D
	4	4	U
	4½	5	C
Very hard	4¾	6	T
	5		
	6		

TABLE 11.—(*Concluded*).

Safety Emery Wheel Company's Method

Vitrified wheels

Extremely soft	C, C½	Medium hard	I, I¼, I½, I¾
Very soft	H, H½	Hard	O, O¼, O½, O¾, N
Soft	A, A¼, A½, A¾	Very hard	N¼, N½
Medium soft	M, M¼, M½, M¾		
Medium	P, P¼, P½, P¾		

Silicate wheels

Extra hard	1, 1½, 2	Soft	4½
Hard	2½	Very soft	5, 5½
Medium hard	3	Extra soft	6, 6½
Medium	3½	Extremely soft	7
Medium soft	4		

Table 12.—Gear Wheels

TABLE OF TOOTH PARTS—DIAMETRAL PITCH IN FIRST COLUMN

Diametral Pitch	Circular Pitch	Thickness of Tooth on Pitch Line	Addendum and $\frac{1''}{P}$	Working Depth of Tooth	Depth of Space below Pitch Line	Whole Depth of Tooth
P	P'	t	s	D''	$s+f$	$D''+f$
2	1.5708	.7854	.5000	1.0000	.5785	1.0785
2¼	1.3963	.6981	.4444	.8888	.5143	.9587
2½	1.2566	.6283	.4000	.8000	.4628	.8628
2¾	1.1424	.5712	.3636	.7273	.4208	.7844
3	1.0472	.5236	.3333	.6666	.3857	.7190
3½	.8976	.4488	.2857	.5714	.3306	.6163
4	.7854	.3927	.2500	.5000	.2893	.5393
5	.6283	.3142	.2000	.4000	.2314	.4314
6	.5236	.2618	.1666	.3333	.1928	.3595
7	.4488	.2244	.1429	.2857	.1653	.3081
8	.3927	.1963	.1250	.2500	.1446	.2696
9	.3491	.1745	.1111	.2222	.1286	.2397
10	.3142	.1571	.1000	.2000	.1157	.2157
11	.2856	.1428	.0909	.1818	.1052	.1961
12	.2618	.1309	.0833	.1666	.0964	.1798
13	.2417	.1208	.0769	.1538	.0890	.1659
14	.2244	.1122	.0714	.1429	.0826	.1541
15	.2094	.1047	.0666	.1333	.0771	.1438
16	.1963	.0982	.0625	.1250	.0723	.1348
17	.1848	.0924	.0588	.1176	.0681	.1269
18	.1745	.0873	.0555	.1111	.0643	.1198
19	.1653	.0827	.0526	.1053	.0609	.1135
20	.1571	.0785	.0500	.1000	.0579	.1079
22	.1428	.0714	.0455	.0909	.0526	.0980
24	.1309	.0654	.0417	.0833	.0482	.0898
26	.1208	.0604	.0385	.0769	.0445	.0829
28	.1122	.0561	.0357	.0714	.0413	.0770
30	.1047	.0524	.0333	.0666	.0386	.0719

To obtain the size of any part of a diametral pitch not given in the table, divide the corresponding part of 1 diametral pitch by the pitch required.

TABLE 13.—THE DIMENSIONS OF GEARS BY METRIC PITCH

Module is the pitch diameter in mm. divided by the number of teeth in the gear.

Pitch diameter in mm. is the Module multiplied by the number of teeth in the gear.

M = Module.
D' = The pitch diameter of gear.
D = The whole diameter of gear.
N = The number of teeth in gear.
D'' = The working depth of teeth.
t = Thickness of teeth on pitch line.
f = Amount added to depth for clearance.

Then

$$M = \frac{D'}{N} \text{ or } \frac{D}{N+2}.$$

$$D' = N\,M.$$

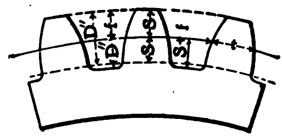
$$D = (N+2)\,M.$$

$$N = \frac{D'}{M} \text{ or } \frac{D}{M} - 2.$$

$$D'' = 2\,M.$$

$$t = M\;1.5708.$$

$$f = \frac{M\;1.5708}{10} = .157\,M.$$



The Module is equal to the part marked "S" in cut, measured in mm. and parts of mm.

Example: Module = 3.50 mm. 100 teeth.
Pitch diameter = 3.5 × 100 = 350 mm.
Whole diameter = (100 + 2) × 3.5 = 357 mm.

PITCHES COMMONLY USED—MODULE IN MILLIMETERS

Module	Corresponding English Diametral Pitch	Module	Corresponding English Diametral Pitch
½ mm.	50.800	4.5 mm.	5.644
¾	33.867	5	5.080
1	25.400	5.5	4.618
1.25	20.320	6	4.233
1.5	16.933	7	3.628
1.75	14.514	8	3.175
2	12.700	9	2.822
2.25	11.288	10	2.540
2.5	10.160	11	2.309
2.75	9.236	12	2.117
3	8.466	14	1.814
3.5	7.257	16	1.587
4	6.350		

TABLE 14.—TOOTH DIMENSIONS OF THE FELLOWS STUB-TOOTH GEAR

Cutters Marked Pitch	Stub Tooth Pitch	Has Depth of Standard Tooth	Thickness on Pitch Line	Addendum	Dedendum and Clearance
4/5	4	5	.3925	.200	.250
5/7	5	7	.314	.1429	.1785
6/8	6	8	.2617	.125	.1562
7/9	7	9	.2243	.111	.1389
8/10	8	10	.1962	.100	.125
9/11	9	11	.1744	.0909	.1137
10/12	10	12	.157	.0833	.1042
12/14	12	14	.1308	.0714	.0893

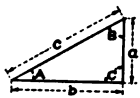
TABLE 15.—PROPORTIONS OF NUTTALL STUB-TOOTH GEARS

The Nuttall Company also use a 20-degree stub tooth, but have a fixed length or depth in the following proportions.

Addendum = .25 × circular pitch instead of .3183.
Dedendum = .25 × circular pitch instead of .3183.
Working depth = .50 × circular pitch instead of .6366.
Clearance = .05 × circular pitch same as standard.
Whole depth = .55 × circular pitch instead of .6866.

TABLE 16.—TRIGONOMETRICAL FORMULAS, ETC.

Geometrical Solution of Right-angled Triangles



$$c = \sqrt{a^2 + b^2}$$

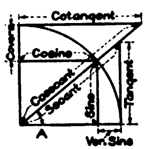
$$b = \sqrt{c^2 - a^2}$$

$$a = \sqrt{c^2 - b^2}$$

$$\sin A = \frac{a}{c} = \frac{\text{opposite side}}{\text{hypotenuse}} \qquad \cos A = \frac{b}{c} = \frac{\text{adjacent side}}{\text{hypotenuse}}$$

$$\tan A = \frac{a}{b} = \frac{\text{opposite side}}{\text{adjacent side}} \qquad \cot A = \frac{b}{a} = \frac{\text{adjacent side}}{\text{opposite side}}$$

$$\sec A = \frac{c}{b} = \frac{\text{hypotenuse}}{\text{adjacent side}} \qquad \text{cosec } A = \frac{c}{a} = \frac{\text{hypotenuse}}{\text{opposite side}}$$



General Equivalents

The illustration shows the different trigonometrical expressions in terms of the angle A.

In the following formulas the radius = 1.

Complement of an angle = its difference from 90°.
Supplement of an angle = its difference from 180°.

$$\text{Sin} = \frac{1}{\text{cosec}} = \frac{\text{cos}}{\text{cot}} = \sqrt{(1 - \text{cos}^2)}$$

$$\text{Cos} = \sqrt{(1 - \text{sin}^2)} = \frac{\text{sin}}{\text{tan}} = \text{sin} \times \text{cot} = \frac{1}{\text{sec}}$$

$$\text{Sec} = \sqrt{\text{rad}^2 + \text{tan}^2} = \frac{1}{\text{cos}} = \frac{\text{tan}}{\text{sin}} \qquad \text{Cosec} = \frac{1}{\text{sin}}$$

$$\text{Tan} = \frac{\text{sin}}{\text{cos}} = \frac{1}{\text{cot}} \qquad \text{Cot} = \frac{\text{cos}}{\text{sin}} = \frac{1}{\text{tan}}$$

$$\text{Versin} = \text{rad} - \text{cos} \qquad \text{Coversin} = \text{rad} - \text{sin}$$

$$\text{Rad} = \text{tan} \times \text{cot} = \sqrt{\text{sin}^2 + \text{cos}^2}$$

Table 17.—Trigonometric Functions

Angles	Sines		Cosines		Tangents		Cotangents		Angles
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
0° 00′	.0000	∞	1.0000	0.0000	.0000	∞	∞	∞	90° 00′
10	.0029	7.4637	1.0000	0000	.0029	7.4637	343.77	2.5363	50
20	.0058	7648	1.0000	0000	.0058	7648	171.89	2352	40
30	.0087	9408	1.0000	0000	.0087	9409	114.59	0591	30
40	.0116	8.0658	.9999	0000	.0116	8.0658	85.940	1.9342	20
50	.0145	1627	.9999	0000	.0145	1627	68.750	8373	10
1° 00′	.0175	8.2419	.9998	9.9999	.0175	8.2419	57.290	1.7581	89° 00′
10	.0204	3088	.9998	9999	.0204	3089	49.104	6911	50
20	.0233	3668	.9997	9999	.0233	3669	42.964	6331	40
30	.0262	4179	.9997	9999	.0262	4181	38.188	5819	30
40	.0291	4637	.9996	9998	.0291	4638	34.368	5362	20
50	.0320	5050	.9995	9998	.0320	5053	31.242	4947	10
2° 00′	.0349	8.5428	.9994	9.9997	.0349	8.5431	28.636	1.4569	88° 00′
10	.0378	5776	.9993	9997	.0378	5779	26.432	4221	50
20	.0407	6097	.9992	9996	.0407	6101	24.542	3899	40
30	.0436	6397	.9990	9996	.0437	6401	22.904	3599	30
40	.0465	6677	.9989	9995	.0466	6682	21.470	3318	20
50	.0494	6940	.9988	9995	.0495	6945	20.206	3055	10
3° 00′	.0523	8.7188	.9986	9.9994	.0524	8.7194	19.081	1.2806	87° 00′
10	.0552	7423	.9985	9993	.0553	7429	18.075	2571	50
20	.0581	7645	.9983	9993	.0582	7652	17.169	2348	40
30	.0610	7857	.9981	9992	.0612	7865	16.350	2135	30
40	.0640	8059	.9980	9991	.0641	8067	15.605	1933	20
50	.0669	8251	.9978	9990	.0670	8261	14.924	1739	10
4° 00′	.0698	8.8436	.9976	9.9989	.0699	8.8446	14.301	1.1554	86° 00′
10	.0727	8613	.9974	9989	.0729	8624	13.727	1376	50
20	.0756	8783	.9971	9988	.0758	8795	13.197	1205	40
30	.0785	8946	.9969	9987	.0787	8960	12.706	1040	30
40	.0814	9104	.9967	9986	.0816	9118	12.251	0882	20
50	.0843	9256	.9964	9985	.0846	9272	11.826	0728	10
5° 00′	.0872	8.9403	.9962	9.9983	.0875	8.9420	11.430	1.0580	85° 00′
10	.0901	9545	.9959	9982	.0904	9563	11.059	0437	50
20	.0929	9682	.9957	9981	.0934	9701	10.712	0299	40
30	.0958	9816	.9954	9980	.0963	9836	10.385	0164	30
40	.0987	9945	.9951	9979	.0992	9966	10.078	0034	20
50	.1016	9.0070	.9948	9977	.1022	9.0093	9.7882	0.9907	10
6° 00′	.1045	9.0192	.9945	9.9976	.1051	9.0216	9.5144	0.9784	84° 00′
10	.1074	0311	.9942	9975	.1080	0336	9.2553	9664	50
20	.1103	0426	.9939	9973	.1110	0453	9.0098	9547	40
30	.1132	0539	.9936	9972	.1139	0567	8.7769	9433	30
40	.1161	0648	.9932	9971	.1169	0678	8.5555	9322	20
50	.1190	0755	.9929	9969	.1198	0786	8.3450	9214	10
7° 00′	.1219	9.0859	.9925	9.9968	.1228	9.0891	8.1443	0.9109	83° 00′
10	.1248	0961	.9922	9966	.1257	0995	7.9530	9005	50
20	.1276	1060	.9918	9964	.1287	1096	7.7704	8904	40
30	.1305	1157	.9914	9963	.1317	1194	7.5958	8806	30
40	.1334	1252	.9911	9961	.1346	1291	7.4287	8709	20
50	.1363	1345	.9907	9959	.1376	1385	7.2687	8615	10
8° 00′	.1392	9.1436	.9903	9.9958	.1405	9.1478	7.1154	0.8522	82° 00′
10	.1421	1525	.9899	9956	.1435	1569	6.9682	8431	50
20	.1449	1612	.9894	9954	.1465	1658	6.8269	8342	40
30	.1478	1697	.9890	9952	.1495	1745	6.6912	8255	30
40	.1507	1781	.9886	9950	.1524	1831	6.5606	8169	20
50	.1536	1863	.9881	9948	.1554	1915	6.4348	8085	10
9° 00′	.1564	9.1943	.9877	9.9946	.1584	9.1997	6.3138	0.8003	81° 00′
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
Angles	Cosines		Sines		Cotangents		Tangents		Angles

TABLE 17.—(*Continued*)

Angles	Sines Nat.	Sines Log.	Cosines Nat.	Cosines Log.	Tangents Nat.	Tangents Log.	Cotangents Nat.	Cotangents Log.	Angles
9° 00′	.1564	9.1943	.9877	9.9946	.1584	9.1997	6.3138	0.8003	81° 00′
10	.1593	2022	.9872	9944	.1614	2078	6.1970	7922	50
20	.1622	2100	.9868	9942	.1644	2158	6.0844	7842	40
30	.1650	2176	.9863	9940	.1673	2236	5.9758	7764	30
40	.1679	2251	.9858	9938	.1703	2313	5.8708	7687	20
50	.1708	2324	.9853	9936	.1733	2389	5.7694	7611	10
10° 00′	.1736	9.2397	.9848	9.9934	.1763	9.2463	5.6713	0.7537	80° 00′
10	.1765	2468	.9843	9931	.1793	2536	5.5764	7464	50
20	.1794	2538	.9838	9929	.1823	2609	5.4845	7391	40
30	.1822	2606	.9833	9927	.1853	2680	5.3955	7320	30
40	.1851	2674	.9827	9924	.1883	2750	5.3093	7250	20
50	.1880	2740	.9822	9922	.1914	2819	5.2257	7181	10
11° 00′	.1908	9.2806	.9816	9.9919	.1944	9.2887	5.1446	0.7113	79° 00′
10	.1937	2870	.9811	9917	.1974	2953	5.0658	7047	50
20	.1965	2934	.9805	9914	.2004	3020	4.9894	6980	40
30	.1994	2997	.9799	9912	.2035	3085	4.9152	6915	30
40	.2022	3058	.9793	9909	.2065	3149	4.8430	6851	20
50	.2051	3119	.9787	9907	.2095	3212	4.7729	6788	10
12° 00′	.2079	9.3179	.9781	9.9904	.2126	9.3275	4.7046	0.6725	78° 00′
10	.2108	3238	.9775	9901	.2156	3336	4.6382	6664	50
20	.2136	3296	.9769	9899	.2186	3397	4.5736	6603	40
30	.2164	3353	.9763	9896	.2217	3458	4.5107	6542	30
40	.2193	3410	.9757	9893	.2247	3517	4.4494	6483	20
50	.2221	3466	.9750	9890	.2278	3576	4.3897	6424	10
13° 00′	.2250	9.3521	.9744	9.9887	.2309	9.3634	4.3315	0.6366	77° 00′
10	.2278	3575	.9737	9884	.2339	3691	4.2747	6309	50
20	.2306	3629	.9730	9881	.2370	3748	4.2193	6252	40
30	.2334	3682	.9724	9878	.2401	3804	4.1653	6196	30
40	.2363	3734	.9717	9875	.2432	3859	4.1126	6141	20
50	.2391	3786	.9710	9872	.2462	3914	4.0611	6086	10
14° 00′	.2419	9.3837	.9703	9.9869	.2493	9.3968	4.0108	0.6032	76° 00′
10	.2447	3887	.9696	9866	.2524	4021	3.9617	5979	50
20	.2476	3937	.9689	9863	.2555	4074	3.9136	5926	40
30	.2504	3986	.9681	9859	.2586	4127	3.8667	5873	30
40	.2532	4035	.9674	9856	.2617	4178	3.8208	5822	20
50	.2560	4083	.9667	9853	.2648	4230	3.7760	5770	10
15° 00′	.2588	9.4130	.9659	9.9849	.2679	9.4281	3.7321	0.5719	75° 00′
10	.2616	4177	.9652	9846	.2711	4331	3.6891	5669	50
20	.2644	4223	.9644	9843	.2742	4381	3.6470	5619	40
30	.2672	4269	.9636	9839	.2773	4430	3.6059	5570	30
40	.2700	4314	.9628	9836	.2805	4479	3.5656	5521	20
50	.2728	4359	.9621	9832	.2836	4527	3.5261	5473	10
16° 00′	.2756	9.4403	.9613	9.9828	.2867	9.4575	3.4874	0.5425	74° 00′
10	.2784	4447	.9605	9825	.2899	4622	3.4495	5378	50
20	.2812	4491	.9596	9821	.2931	4669	3.4124	5331	40
30	.2840	4533	.9588	9817	.2962	4716	3.3759	5284	30
40	.2868	4576	.9580	9814	.2994	4762	3.3402	5238	20
50	.2896	4618	.9572	9810	.3026	4808	3.3052	5192	10
17° 00′	.2924	9.4659	.9563	9.9806	.3057	9.4853	3.2709	0.5147	73° 00′
10	.2952	4700	.9555	9802	.3089	4898	3.2371	5102	50
20	.2979	4741	.9546	9798	.3121	4943	3.2041	5057	40
30	.3007	4781	.9537	9794	.3153	4987	3.1716	5013	30
40	.3035	4821	.9528	9790	.3185	5031	3.1397	4969	20
50	.3062	4861	.9520	9786	.3217	5075	3.1084	4925	10
18° 00′	.3090	9.4900	.9511	9.9782	.3249	9.5118	3.0777	0.4882	72° 00′
Angles	Cosines Nat.	Cosines Log.	Sines Nat.	Sines Log.	Cotangents Nat.	Cotangents Log.	Tangents Nat.	Tangents Log.	Angles

TABLE 17.—(*Continued*).

Angles	Sines Nat.	Sines Log.	Cosines Nat.	Cosines Log.	Tangents Nat.	Tangents Log.	Cotangents Nat.	Cotangents Log.	Angles
18° 00′	.3090	9.4900	.9511	9.9782	.3249	9.5118	3.0777	0.4882	72° 00′
10	.3118	4939	.9502	9778	.3281	5161	3.0475	4839	50
20	.3145	4977	.9492	9774	.3314	5203	3.0178	4797	40
30	.3173	5015	.9483	9770	.3346	5245	2.9887	4755	30
40	.3201	5052	.9474	9765	.3378	5287	2.9600	4713	20
50	.3228	5090	.9465	9761	.3411	5329	2.9319	4671	10
19° 00′	.3256	9.5126	.9455	9.9757	.3443	9.5370	2.9042	0.4630	71° 00′
10	.3283	5163	.9446	9752	.3476	5411	2.8770	4589	50
20	.3311	5199	.9436	9748	.3508	5451	2.8502	4549	40
30	.3338	5235	.9426	9743	.3541	5491	2.8239	4509	30
40	.3365	5270	.9417	9739	.3574	5531	2.7980	4469	20
50	.3393	5306	.9407	9734	.3607	5571	2.7725	4429	10
20° 00′	.3420	9.5341	.9397	9.9730	.3640	9.5611	2.7475	0.4389	70° 00′
10	.3448	5375	.9387	9725	.3673	5650	2.7228	4350	50
20	.3475	5409	.9377	9721	.3706	5689	2.6985	4311	40
30	.3502	5443	.9367	9716	.3739	5727	2.6746	4273	30
40	.3529	5477	.9356	9711	.3772	5766	2.6511	4234	20
50	.3557	5510	.9346	9706	.3805	5804	2.6279	4196	10
21° 00′	.3584	9.5543	.9336	9.9702	.3839	9.5842	2.6051	0.4158	69° 00′
10	.3611	5576	.9325	9697	.3872	5879	2.5826	4121	50
20	.3638	5609	.9315	9692	.3906	5917	2.5605	4083	40
30	.3665	5641	.9304	9687	.3939	5954	2.5386	4046	30
40	.3692	5673	.9293	9682	.3973	5991	2.5172	4009	20
50	.3719	5704	.9283	9677	.4006	6028	2.4960	3972	10
22° 00′	.3746	9.5736	.9272	9.9672	.4040	9.6064	2.4751	0.3936	68° 00′
10	.3773	5767	.9261	9667	.4074	6100	2.4545	3900	50
20	.3800	5798	.9250	9661	.4108	6136	2.4342	3864	40
30	.3827	5828	.9239	9656	.4142	6172	2.4142	3828	30
40	.3854	5859	.9228	9651	.4176	6208	2.3945	3792	20
50	.3881	5889	.9216	9646	.4210	6243	2.3750	3757	10
23° 00′	.3907	9.5919	.9205	9.9640	.4245	9.6279	2.3559	0.3721	67° 00′
10	.3934	5948	.9194	9635	.4279	6314	2.3369	3686	50
20	.3961	5978	.9182	9629	.4314	6348	2.3183	3652	40
30	.3987	6007	.9171	9624	.4348	6383	2.2998	3617	30
40	.4014	6036	.9159	9618	.4383	6417	2.2817	3583	20
50	.4041	6065	.9147	9613	.4417	6452	2.2637	3548	10
24° 00′	.4067	9.6093	.9135	9.9607	.4452	9.6486	2.2460	0.3514	66° 00′
10	.4094	6121	.9124	9602	.4487	6520	2.2286	3480	50
20	.4120	6149	.9112	9596	.4522	6553	2.2113	3447	40
30	.4147	6177	.9100	9590	.4557	6587	2.1943	3413	30
40	.4173	6205	.9088	9584	.4592	6620	2.1775	3380	20
50	.4200	6232	.9075	9579	.4628	6654	2.1609	3346	10
25° 00′	.4226	9.6259	.9063	9.9573	.4663	9.6687	2.1445	0.3313	65° 00′
10	.4253	6286	.9051	9567	.4699	6720	2.1283	3280	50
20	.4279	6313	.9038	9561	.4734	6752	2.1123	3248	40
30	.4305	6340	.9026	9555	.4770	6785	2.0965	3215	30
40	.4331	6366	.9013	9549	.4806	6817	2.0809	3183	20
50	.4358	6392	.9001	9543	.4841	6850	2.0655	3150	10
26° 00′	.4384	9.6418	.8988	9.9537	.4877	9.6882	2.0503	0.3118	64° 00′
10	.4410	6444	.8975	9530	.4913	6914	2.0353	3086	50
20	.4436	6470	.8962	9524	.4950	6946	2.0204	3054	40
30	.4462	6495	.8949	9518	.4986	6977	2.0057	3023	30′
40	.4488	6521	.8936	9512	.5022	7009	1.9912	2991	20
50	.4514	6546	.8923	9505	.5059	7040	1.9768	2960	10
27° 00′	.4540	9.6570	.8910	9.9499	.5095	9.7072	1.9626	0.2928	63° 00′
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
Angles	Cosines		Sines		Cotangents		Tangents		Angles

TABLE 17.—TRIGONOMETRIC FUNCTIONS.—(*Continued*).

Angles	Sines		Cosines		Tangents		Cotangents		Angles
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
27° 00′	.4540	9.6570	.8910	9.9499	.5095	9.7072	1.9626	0.2928	63° 00′
10	.4566	6595	.8897	9492	.5132	7103	1.9486	2897	50
20	.4592	6620	.8884	9486	.5169	7134	1.9347	2866	40
30	.4617	6644	.8870	9479	.5206	7165	1.9210	2835	30
40	.4643	6668	.8857	9473	.5243	7196	1.9074	2804	20
50	.4669	6692	.8843	9466	.5280	7226	1.8940	2774	10
28° 00′	.4695	9.6716	.8829	9.9459	.5317	9.7257	1.8807	0.2743	62° 00′
10	.4720	6740	.8816	9453	.5354	7287	1.8676	2713	50
20	.4746	6763	.8802	9446	.5392	7317	1.8546	2683	40
30	.4772	6787	.8788	9439	.5430	7348	1.8418	2652	30
40	.4797	6810	.8774	9432	.5467	7378	1.8291	2622	20
50	.4823	6833	.8760	9425	.5505	7408	1.8165	2592	10
29° 00′	.4848	9.6856	.8746	9.9418	.5543	9.7438	1.8040	0.2562	61° 00′
10	.4874	6878	.8732	9411	.5581	7467	1.7917	2533	50
20	.4899	6901	.8718	9404	.5619	7497	1.7796	2503	40
30	.4924	6923	.8704	9397	.5658	7526	1.7675	2474	30
40	.4950	6946	.8689	9390	.5696	7556	1.7556	2444	20
50	.4975	6968	.8675	9383	.5735	7585	1.7437	2415	10
30° 00′	.5000	9.6990	.8660	9.9375	.5774	9.7614	1.7321	0.2386	60° 00′
10	.5025	7012	.8646	9368	.5812	7644	1.7205	2356	50
20	.5050	7033	.8631	9361	.5851	7673	1.7090	2327	40
30	.5075	7055	.8616	9353	.5890	7701	1.6977	2299	30
40	.5100	7076	.8601	9346	.5930	7730	1.6864	2270	20
50	.5125	7097	.8587	9338	.5969	7759	1.6753	2241	10
31° 00′	.5150	9.7118	.8572	9.9331	.6009	9.7788	1.6643	0.2212	59° 00′
10	.5175	7139	.8557	9323	.6048	7816	1.6534	2184	50
20	.5200	7160	.8542	9315	.6088	7845	1.6426	2155	40
30	.5225	7181	.8526	9308	.6128	7873	1.6319	2127	30
40	.5250	7201	.8511	9300	.6168	7902	1.6212	2098	20
50	.5275	7222	.8496	9292	.6208	7930	1.6107	2070	10
32° 00′	.5299	9.7242	.8480	9.9284	.6249	9.7958	1.6003	0.2042	58° 00′
10	.5324	7262	.8465	9276	.6289	7986	1.5900	2014	50
20	.5348	7282	.8450	9268	.6330	8014	1.5798	1986	40
30	.5373	7302	.8434	9260	.6371	8042	1.5697	1958	30
40	.5398	7322	.8418	9252	.6412	8070	1.5597	1930	20
50	.5422	7342	.8403	9244	.6453	8097	1.5497	1903	10
33° 00′	.5446	9.7361	.8387	9.9236	.6494	9.8125	1.5399	0.1875	57° 00′
10	.5471	7380	.8371	9228	.6536	8153	1.5301	1847	50
20	.5495	7400	.8355	9219	.6577	8180	1.5204	1820	40
30	.5519	7419	.8339	9211	.6619	8208	1.5108	1792	30
40	.5544	7438	.8323	9203	.6661	8235	1.5013	1765	20
50	.5568	7457	.8307	9194	.6703	8263	1.4919	1737	10
34° 00′	.5592	9.7476	.8290	9.9186	.6745	9.8290	1.4826	0.1710	56° 00′
10	.5616	7494	.8274	9177	.6787	8317	1.4733	1683	50
20	.5640	7513	.8258	9169	.6830	8344	1.4641	1656	40
30	.5664	7531	.8241	9160	.6873	8371	1.4550	1629	30
40	.5688	7550	.8225	9151	.6916	8398	1.4460	1602	20
50	.5712	7568	.8208	9142	.6959	8425	1.4370	1575	10
35° 00′	.5736	9.7586	.8192	9.9134	.7002	9.8452	1.4281	0.1548	55° 00′
10	.5760	7604	.8175	9125	.7046	8479	1.4193	1521	50
20	.5783	7622	.8158	9116	.7089	8506	1.4106	1494	40
30	.5807	7640	.8141	9107	.7133	8533	1.4019	1467	30
40	.5831	7657	.8124	9098	.7177	8559	1.3934	1441	20
50	.5854	7675	.8107	9089	.7221	8586	1.3848	1414	10
36° 00′	.5878	9.7692	.8090	9.9080	.7265	9.8613	1.3764	0.1387	54° 00′
	Nat.	Log.	Nat.	Log.	Nat.	Log.	Nat.	Log.	
Angles	Cosines		Sines		Cotangents		Tangents		Angles

TABLE 17.—TRIGONOMETRIC FUNCTIONS.—(*Concluded*).

Angles	Sines Nat.	Sines Log.	Cosines Nat.	Cosines Log.	Tangents Nat.	Tangents Log.	Cotangents Nat.	Cotangents Log.	Angles
36° 00′	.5878	9.7692	.8090	9.9080	.7265	9.8613	1.3764	0.1387	54° 00′
10	.5901	7710	.8073	9070	.7310	8639	1.3680	1361	50
20	.5925	7727	.8056	9061	.7355	8666	1.3597	1334	40
30	.5948	7744	.8039	9052	.7400	8692	1.3514	1308	30
40	.5972	7761	.8021	9042	.7445	8718	1.3432	1282	20
50	.5995	7778	.8004	9033	.7490	8745	1.3351	1255	10
37° 00′	.6018	9.7795	.7986	9.9023	.7536	9.8771	1.3270	0.1229	53° 00′
10	.6041	7811	.7969	9014	.7581	8797	1.3190	1203	50
20	.6065	7828	.7951	9004	.7627	8824	1.3111	1176	40
30	.6088	7844	.7934	8995	.7673	8850	1.3032	1150	30
40	.6111	7861	.7916	8985	.7720	8876	1.2954	1124	20
50	.6134	7877	.7898	8975	.7766	8902	1.2876	1098	10
38° 00′	.6157	9.7893	.7880	9.8965	.7813	9.8928	1.2799	0.1072	52° 00′
10	.6180	7910	.7862	8955	.7860	8954	1.2723	1046	50
20	.6202	7926	.7844	8945	.7907	8980	1.2647	1020	40
30	.6225	7941	.7826	8935	.7954	9006	1.2572	0994	30
40	.6248	7957	.7808	8925	.8002	9032	1.2497	0968	20
50	.6271	7973	.7790	8915	.8050	9058	1.2423	0942	10
39° 00′	.6293	9.7989	.7771	9.8905	.8098	9.9084	1.2349	0.0916	51° 00′
10	.6316	8004	.7753	8895	.8146	9110	1.2276	0890	50
20	.6338	8020	.7735	8884	.8195	9135	1.2203	0865	40
30	.6361	8035	.7716	8874	.8243	9161	1.2131	0839	30
40	.6383	8050	.7698	8864	.8292	9187	1.2059	0813	20
50	.6406	8066	.7679	8853	.8342	9212	1.1988	0788	10
40° 00′	.6428	9.8081	.7660	9.8843	.8391	9.9238	1.1918	0.0762	50° 00′
10	.6450	8096	.7642	8832	.8441	9264	1.1847	0736	50
20	.6472	8111	.7623	8821	.8491	9289	1.1778	0711	40
30	.6494	8125	.7604	8810	.8541	9315	1.1708	0685	30
40	.6517	8140	.7585	8800	.8591	9341	1.1640	0659	20
50	.6539	8155	.7566	8789	.8642	9366	1.1571	0634	10
41° 00′	.6561	9.8169	.7547	9.8778	.8693	9.9392	1.1504	0.0608	49° 00′
10	.6583	8184	.7528	8767	.8744	9417	1.1436	0583	50
20	.6604	8198	.7509	8756	.8796	9443	1.1369	0557	40
30	.6626	8213	.7490	8745	.8847	9468	1.1303	0532	30
40	.6648	8227	.7470	8733	.8899	9494	1.1237	0506	20
50	.6670	8241	.7451	8722	.8952	9519	1.1171	0481	10
42° 00′	.6691	9.8255	.7431	9.8711	.9004	9.9544	1.1106	0.0456	48° 00′
10	.6713	8269	.7412	8699	.9057	9570	1.1041	0430	50
20	.6734	8283	.7392	8688	.9110	9595	1.0977	0405	40
30	.6756	8297	.7373	8676	.9163	9621	1.0913	0379	30
40	.6777	8311	.7353	8665	.9217	9646	1.0850	0354	20
50	.6799	8324	.7333	8653	.9271	9671	1.0786	0329	10
43° 00′	.6820	9.8338	.7314	9.8641	.9325	9.9697	1.0724	0.0303	47° 00′
10	.6841	8351	.7294	8629	.9380	9722	1.0661	0278	50
20	.6862	8365	.7274	8618	.9435	9747	1.0599	0253	40
30	.6884	8378	.7254	8606	.9490	9772	1.0538	0228	30
40	.6905	8391	.7234	8594	.9545	9798	1.0477	0202	20
50	.6926	8405	.7214	8582	.9601	9823	1.0416	0177	10
44° 00′	.6947	9.8418	.7193	9.8569	.9657	9.9848	1.0355	0.0152	46° 00′
10	.6967	8431	.7173	8557	.9713	9874	1.0295	0126	50
20	.6988	8444	.7153	8545	.9770	9899	1.0235	0101	40
30	.7009	8457	.7133	8532	.9827	9924	1.0176	0076	30
40	.7030	8469	.7112	8520	.9884	9949	1.0117	0051	20
50	.7050	8482	.7092	8507	.9942	9975	1.0058	0025	10
45° 00′	.7071	9.8495	.7071	9.8495	1.0000	0.0000	1.0000	0.0000	45° 00′
Angles	Cosines Nat.	Cosines Log.	Sines Nat.	Sines Log.	Cotangents Nat.	Cotangents Log.	Tangents Nat.	Tangents Log.	Angles

TABLE 18.—DECIMAL EQUIVALENTS OF THE NUMBER AND LETTER SIZES OF TWIST DRILLS

No.	Size in decimals	No.	Size in decimals	No.	Size in decimals	No.	Size in decimals
1	.2280	21	.1590	41	.0960	61	.0390
2	.2210	22	.1570	42	.0935	62	.0380
3	.2130	23	.1540	43	.0890	63	.0370
4	.2090	24	.1520	44	.0860	64	.0360
5	.2055	25	.1495	45	.0820	65	.0350
6	.2040	26	.1470	46	.0810	66	.0330
7	.2010	27	.1440	47	.0785	67	.0320
8	.1990	28	.1405	48	.0760	68	.0310
9	.1960	29	.1360	49	.0730	69	.02925
10	.1935	30	.1285	50	.0700	70	.0280
11	.1910	31	.1200	51	.0670	71	.0260
12	.1890	32	.1160	52	.0635	72	.0250
13	.1850	33	.1130	53	.0595	73	.0240
14	.1820	34	.1110	54	.0550	74	.0225
15	.1800	35	.1100	55	.0520	75	.0210
16	.1770	36	.1065	56	.0465	76	.0200
17	.1730	37	.1040	57	.0430	77	.0180
18	.1695	38	.1015	58	.0420	78	.0160
19	.1660	39	.0995	59	.0410	79	.0145
20	.1610	40	.0980	60	.0400	80	.0135

LETTER SIZES OF DRILLS

Letter	Size in decimals	Letter	Size in decimals
A 15/64	.234	N	.302
B	.238	O 5/16	.316
C	.242	P 21/64	.323
D	.246	Q	.332
E 1/4	.250	R 11/32	.339
F	.257	S	.348
G	.261	T 23/64	.358
H 17/64	.266	U	.368
I	.272	V 3/8	.377
J	.277	W 25/64	.386
K 9/32	.281	X	.397
L	.290	Y 13/32	.404
M 19/64	.295	Z	.413

TABLE 19.—MACHINE SCREW SIZES

Sizes marked* are A.S.M.E. Standard

Tap Drill Sizes calculated from the formula $\left(O.\ D. - \frac{0.9}{N}\right)$ which gives a trifle over ⅔ of a full thread. See page 39.

Outside diam. (O. D.)	Nearest number, letter or fractional size body drill	Screw gauge No.	No. of threads per in. (N)	Root diam. exact (R. D.)	Tap drill diam. $\left(O.D.-\frac{0.9}{N}\right)$	Nearest number, letter or fractional size tap drill	Pitch diam. or screw thread micrometer reading
.060	#52–.0635	0	80*	.0438	.049	#56–.0465	.0519
.073	#49–.073	1	72*	.055	.060	#53–.0595	.064
		1					
.0842	#44–.086	2	48	.0565	.065	#52–.0635	.0704
.0842	" "	2	56	.0612	.068	#51–.067	.0727
.086	" "	2	64*	.0657	.072	#50–.070	.0759
.0973	#39–.0995	3	40	.0649	.074	#49–.073	.0811
.0973	" "	3	48	.0696	.078	#48–.076	.0835
.099	" "	3	56*	.0758	.083	#45–.082	.0874
.1105	#33–.113	4	32	.0699	.082	#45–.082	.0902
.1105	" "	4	36	.0744	.085	#45–.082	.0924
.1105	" "	4	40	.0781	.088	#44–.086	.0943
.112	" "	4	48*	.0849	.093	#42–.0935	.0985
.1236	⅛″ or #30–.1285	5	30	.0803	.093	#42–.0935	.1019
.1236	" "	5	32	.083	.095	#42–.0935	.1033
.1236	" "	5	36	.0875	.098	#40–.098	.1055
.1236	" "	5	40	.0912	.101	#39–.0995	.1074
.125	" "	5	44*	.0955	.104	#37–.104	.1102
.1368	#28–.1405	6	30	.0935	.106	#36–.1065	.1151
.1368	" "	6	32	.0962	.108	#36–.1065	.1165
.1368	" "	6	36	.1007	.111	#34–.111	.1187
.138	" "	6	40*	.1055	.115	#33–.113	.1218
.150	#24–.152	7	28	.1036	.118	#32–.116	.1268
.150	" "	7	30	.1067	.120	#31–.120	.1283
.150	" "	7	32	.1094	.122	#31–.120	.1297
.151	" "	7	36*	.1149	.125	⅛″ or #31	.133

TABLE 19.—(*Continued*).

Outside diam. (O. D.)	Nearest number, letter or fractional size body drill	Screw gauge No.	No. of threads per in. (N)	Root diam. exact (R. D.)	Tap drill diam. $\left(\text{O.D.} - \frac{0.9}{N}\right)$	Nearest number, letter or fractional size tap drill	Pitch diam. or screw thread micrometer reading
.1631	#19–.166	8	24	.109	.125	1/8" or #31	.136
.1631	" "	8	30	.1198	.133	#30–.1285	.1414
.1631	" "	8	32	.1225	.135	#29–.136	.1428
.164	" "	8	36*	.1279	.139	#29–.136	.146
.1763	#16–.177	9	24	.1222	.138	#29–.136	.1492
.1763	" "	9	28	.1299	.144	#27–.144	.1531
.1763	" "	9	30	.1330	.146	#27–.144	.1546
.177	" "	9	32*	.1364	.148	#26–.147	.1567
.1894	#11–.191	10	24	.1353	.151	#25–.1495	.1623
.190	" "	10	30*	.1467	.160	#21–.159	.1684
.1894	" "	10	32	.1488	.161	#20–.161	.1691
.2026	#6–.204	11	24	.1485	.165	#19–.166	.1755
.2026	" "	11	28	.156	.170	#18–.1695	.1793
.2026	" "	11	30	.159	.172	#18–.1695	.1808
.2158	7/32–.218	12	20	.1508	.170	#18–.1695	.1833
.2158	" "	12	22	.1568	.174	#17–.174	.1863
.2158	" "	12	24	.1617	.178	#16–.177	.1887
.216	" "	12	28*	.1696	.183	#14–.182	.1928
.2289	15/64–.234	13	20	.1639	.183	#14–.182	.1964
.2289	" "	13	22	.1699	.188	#13–.185	.1994
.2289	" "	13	24	.1748	.191	#11–.191	.2018
	" "						
.2421	D–.246	14	18	.170	.192	#11–.192	.206
.2421	" "	14	20	.1771	.197	#9–.196	.2096
.2421	" "	14	22	.1831	.201	#7–.201	.2126
.242	" "	14	24*	.1879	.204	#6–.204	.2149
.2552	F–.257	15	18	.1831	.205	#6–.204	.2191
.2552	" "	15	20	.1902	.210	#4–.209	.2227
.2552	" "	15	22	.1962	.214	#3–.213	.2257
.2552	" "	15	24	.2013	.217	#3–.213	.2282

TABLE 19.—(*Continued*).

Outside diam. (O. D.)	Nearest number, letter or fractional size body drill	Screw gauge No.	No. of threads per in. (N)	Root diam. exact (R. D.)	Tap drill diam. $\left(\text{O.D.}-\frac{0.9}{N}\right)$	Nearest number, letter or fractional size tap drill	Pitch diam. or screw thread micrometer reading
.2684	I–.272	16	16	.1873	.212	#3–.213	.2278
.2684	" "	16	18	.1963	.218	#3–.213	.2323
.2684	" "	16	20	.2034	.223	#2–.221	.2359
.268	" "	16	22*	.209	.227	#1–.228	.2385
.2816	L–.290	17	16	.2005	.225	#2–.221	.241
.2816	" "	17	18	.2095	.231	#1–.228	.2455
.2816	" "	17	20	.2166	.236	15/64–.234	.2491
.2947	19/64–.296	18	16	.2136	.238	15/64–.234	.2541
.2947	" "	18	18	.2226	.244	C–.242	.2586
.294	" "	18	20*	.229	.249	D–.246	.2615
.3079	5/16–.312	19	16	.2268	.251	1/4–.250	.2673
.3079	" "	19	18	.2358	.257	F–.257	.2718
.3079	" "	19	20	.2429	.262	G–.261	.2754
.321	P–.323	20	16	.2399	.264	17/64–.266	.2804
.321	" "	20	18	.2489	.271	17/64–.266	.2849
.320	" "	20	20*	.255	.275	I–.272	.2875
.3474	S–.348	22	16	.2663	.291	L–.290	.3068
.346	" "	22	18*	.2738	.296	19/64–.297	.3099
.3737	3/8–.375	24	14	.2809	.309	N–.302	.3273
.372	" "	24	16*	.2908	.315	5/16–.312	.3314
.3737	" "	24	18	.3016	.323	P–.323	.3376
.400	13/32–.406	26	14	.3072	.335	Q–.332	.3536
.398	" "	26	16*	.3168	.341	11/32–.344	.3574
.424	7/16–.437	28	14*	.3312	.359	23/64–.359	.3776
.4263	" "	28	16	.3452	.370	U–.368	.3857
.450	29/64–.453	30	14*	.3572	.385	W–.386	.4036
.4526	" "	30	16	.3715	.396	X–.397	.412

TABLE 20.—UNITED STATES STANDARD SCREW SIZES

(Tap drill sizes calculated from the formula $O.D. - \frac{0.9}{N}$ which gives a trifle over ⅔ of a full thread. See page 39)

Outside diameter (*O.D.*)	Number of threads per inch	Root diameter (exact) *R.D.*	Tap drill diameter $\left(O.D. - \frac{0.9}{N}\right)$	Nearest number letter or fractional size tap drill	Pitch diameter (screw thread micrometer reading)
¼	20	0.185	0.205	#6 –0.204	0.2175
5/16	18	0.2403	0.262	*G*–0.261	0.2764
⅜	16	0.2936	0.319	5/16 –0.312	0.3344
7/16	14	0.3447	0.373	*U*–0.368	0.3911
½	13	0.4001	0.431	27/64–0.421	0.4501
9/16	12	0.4542	0.485	31/64–0.484	0.5084
⅝	11	0.5069	0.544	17/32–0.531	0.566
¾	10	0.6201	0.660	21/32–0.656	0.6851
⅞	9	0.7307	0.775	49/64–0.766	0.8029
1	8	0.8376	0.888	⅞ –0.875	0.9188
1⅛	7	0.9394	0.995	63/64–0.984	1.0322
1¼	7	1.0644	1.120	1⅛ –1.125	1.1572
1⅜	6	1.1585	1.225	1 3/16 –1.187	1.2668
1½	6	1.2835	1.350	1 5/16 –1.312	1.3918
1⅝	5½	1.3888	1.461	1 7/16 –1.437	1.507
1¾	5	1.4902	1.570	1 9/16 –1.562	1.6201
1⅞	5	1.6152	1.695	1 11/16–1.687	1.7451
2	4½	1.7113	1.800	1¾ –1.750	1.8557

Table 21.—S. A. E. Standard Screw Sizes

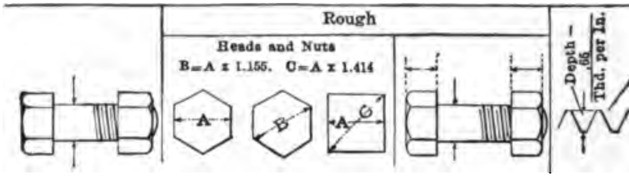
(Tap drill sizes calculated from the formula $O.D. - \frac{0.9}{N}$ which gives a trifle over 2/3 of a full thread. See page 39)

Outside diameter ($O.D.$)	Number of threads per inch	Root diameter (exact) $R.D.$	Tap drill diameter $\left(O.D. - \frac{0.9}{N}\right)$	Nearest number letter or fractional size tap drill	Pitch diameter (screw thread micrometer reading)
1/4	28	0.2036	0.228	#1–0.228	0.2268
5/16	24	0.2584	0.275	I–0.272	0.2854
3/8	24	0.3209	0.338	21/64–0.328	0.3479
7/16	20	0.3725	0.392	25/64–0.390	0.405
1/2	20	0.435	0.455	29/64–0.453	0.4675
9/16	18	0.4903	0.512	1/2 –0.500	0.5264
5/8	18	0.5528	0.575	9/16 –0.562	0.5889
11/16	16	0.6063	0.631	5/8 –0.625	0.6469
3/4	16	0.6688	0.694	11/16–0.687	0.7094
7/8	14	0.7822	0.811	13/16–0.812	0.8344
1	14	0.9072	0.936	15/16–0.937	0.9594

Reasons for Finer Pitches

Threads in automobile work are cut in hard tough materials and do not require to be as coarse as threads cut in cast iron. A screw or bolt of a given size and of finer pitch has greater root diameter and consequently greater strength than a U. S. Std. screw of same size. A fine pitch screw or nut may be set up tighter and does not shake loose as readily as one of coarse pitch.

Table 22.—U. S. Standard Bolts and Nuts
Rough



Dia. of Bolt	Threads per Inch	Across Flats A	Across Corners B	Across Corners C	Thickness Head	Thickness Nut	Depth of Thread
1/4	20	1/2	37/64	23/32	1/4	1/4	.0325
5/16	18	19/32	11/16	27/32	19/64	5/16	.0361
3/8	16	11/16	51/64	31/32	11/32	3/8	.0406
7/16	14	25/32	29/32	1 7/64	25/64	7/16	.0464
1/2	13	7/8	1 1/64	1 1/4	7/16	1/2	.0500
9/16	12	31/32	1 1/8	1 3/8	31/64	9/16	.0542
5/8	11	1 1/16	1 15/64	1 1/2	17/32	5/8	.0590
3/4	10	1 1/4	1 29/64	1 25/32	5/8	3/4	.0650
7/8	9	1 7/16	1 43/64	2 1/32	23/32	7/8	.0722
1	8	1 5/8	1 7/8	2 19/64	13/16	1	.0812
1 1/8	7	1 13/16	2 3/32	2 9/16	29/32	1 1/8	.0928
1 1/4	7	2	2 5/16	2 53/64	1	1 1/4	.0928
1 3/8	6	2 3/16	2 17/32	3 3/32	1 3/32	1 3/8	.1083
1 1/2	6	2 3/8	2 3/4	3 23/64	1 3/16	1 1/2	.1083
1 3/4	5	2 3/4	3 3/16	3 57/64	1 3/8	1 3/4	.1300
2	4 1/2	3 1/8	3 39/64	4 27/64	1 9/16	2	.1444
2 1/4	4 1/2	3 1/2	4 3/64	4 61/64	1 3/4	2 1/4	.1444
2 1/2	4	3 7/8	4 31/64	5 31/64	1 15/16	2 1/2	.1625
2 3/4	4	4 1/4	4 29/32	6 1/64	2 1/8	2 3/4	.1625
3	3 1/2	4 5/8	5 11/32	6 17/32	2 5/16	3	.1857

Note. — U. S. Government Standard Bolts and Nuts are made to above U. S. or Sellers' Standard Rough Dimensions. The sizes of finished bolt heads and nuts are the same as the sizes of the rough ones, that is for finished work the forgings must be larger than for rough, thus the same wrench may be used on both black and finished heads and nuts. This excellent practice specified by the Government is now generally followed in all commercial work.

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